Internet Usage Alleviates Depression among the Elderly: A Comprehensive Study

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Abstract

Background: Depression is a widespread mental health issue, significantly affecting the elderly globally. Addressing elderly depression has become a critical health challenge. Despite evidence on digital interventions in developed countries, there is a lack of rigorous research on the potential of internet usage to alleviate depression among the elderly in developing countries.

Objective: This study aims to develop a comprehensive theoretical framework and test hypotheses regarding the impact of internet usage on elderly depression.

Methods: Utilizing data from the China Health and Retirement Longitudinal Study (CHARLS), we employ a two-stage instrumental variable approach to address potential endogeneity and accurately estimate causal effects.

Results: The results demonstrate that internet usage significantly reduces depression levels among the elderly by 1.41%. Mechanism analyses indicate that this reduction is mediated through improved social interaction, increased physical activity, better intergenerational contact, and enhanced educational opportunities. Heterogeneity analyses reveal that these effects are especially pronounced in urban areas, eastern regions, and broadband China pilot zones.

Conclusions: The findings highlight the significant role of internet usage in alleviating depression among the elderly in developing countries, with notable regional variations. This study contributes to the understanding of digital interventions' impact on elderly mental health and suggests the importance of targeted policy interventions to promote internet access and digital literacy. Clinical Trial: Obtained ethical approval from the Biomedical Ethics Review Committee of Peking University (#IRB 00001052 -11015).

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Internet Usage Alleviates Depression among the Elderly: A Comprehensive Study

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ABSTRACT

Background: Depression is a widespread mental health issue, significantly affecting the elderly globally. Addressing elderly depression has become a critical health challenge. Despite evidence on digital interventions in developed countries, there is a lack of rigorous research on the potential of internet usage to alleviate depression among the elderly in developing countries.

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Keywords: Internet usage; Depression; Elderly; Mechanism analysis; Heterogeneity analysis

1 Introduction

Depression is a prevalent psychological and mental health condition. Globally, the prevalence of depression among the elderly population aged 60 and above is 5.7%. This issue is even more pronounced in low- and middle-income countries **(WHO, 2023)**. In China, the prevalence of depression among the elderly is estimated to be as high as 25.55% **(Rong et al., 2020)**. From 2020 to 2050, China's elderly population aged 60 and above is projected to increase from 263 million to 522 million, with its proportion of the total population rising from 18.7% to 39.5% **(Ge et al., 2020)**. Depression significantly affects the quality of life, daily activities, incidence of geriatric diseases, and suicide rates among the elderly **(Guo et al., 2020)**. It not only causes severe harm to the physical and mental health of the elderly but also imposes a significant burden on society. Estimates suggest that healthcare expenditures for individuals with depression are 50% to 100% higher than for those without depression **(Mathers and Loncar, 2006)**. Thus, effectively alleviating depression among the elderly has become an urgent global health issue.

In recent years, information and communication technology has been recognized as a potential factor for alleviating elderly depression **(Lam et al., 2020; Li and Luo, 2024)**. Studies in early-aging countries such as the UK, the US, Japan, and South Korea have confirmed that digital interventions can effectively alleviate depression among the elderly **(Escobar-Viera et al., 2018; Jeon et al., 2020; Minagawa and Saito, 2014)**. As the world’s largest developing country, China

had 119 million elderly internet users by the end of 2021, with an internet penetration rate of 43.2% among the elderly. This raises a critical question: Can internet usage effectively alleviate depression among the elderly in China, and what are the potential mechanisms at play? Unfortunately, the academic community has paid insufficient attention to this issue, with few studies providing rigorous theoretical analysis and empirical evidence. To fill this gap, this paper investigates the causal relationship between internet usage and depression among the elderly from both theoretical and empirical perspectives. The study aims to elucidate the underlying mechanisms and assess the impact of internet usage, thereby providing evidence from developing countries to improve the mental health of the elderly.

The primary challenge of this study is the inherent issue of reverse causality between internet usage and depression among the elderly. Internet usage may influence depression among the elderly, and conversely, depression may affect internet usage among the elderly. This potential endogeneity problem significantly disrupts causal inference, greatly reducing the reliability of the regression coefficients. Existing studies have inadequately addressed this issue. The two-stage instrumental variable (IV) method is widely regarded as one of the most effective approaches to overcome potential endogeneity issues **(Terza et al., 2008)**. By employing an exogenous instrument, this method aims to eliminate the endogeneity of the primary variable, thereby enabling precise estimation of the regression coefficients. This approach requires the instrumental variable to be correlated with the primary variable while being exogenous to the error term.

This paper innovatively employs the National Big Data Comprehensive Pilot Zone policy as an instrumental variable for internet usage, utilizing the two-stage IV method to achieve more accurate causal identification. The National Big Data Comprehensive Pilot Zone policy, through the development of age-friendly applications and digital literacy training, significantly increases internet usage among the elderly, meeting the relevance criterion. Simultaneously, depression among the elderly does not influence the National Big Data Comprehensive Pilot Zone policy, satisfying the exogeneity criterion. Additionally, to further eliminate endogeneity caused by omitted variables, this paper controls for both time-fixed effects and individual-fixed effects in the two-stage IV approach.

Compared to existing studies, this paper offers several potential contributions: First, this study provides a rigorous analysis of the causal relationship between internet usage and depression among the elderly, both theoretically and empirically, thereby contributing to the literature on the mental health of the elderly. Second, it is the first to employ the two-stage instrumental variable (IV) approach for a stringent empirical examination, effectively mitigating endogeneity issues in regression analysis, thereby enriching existing empirical methodologies. Third, this paper conducts a heterogeneity analysis across different regions, expanding on current research that mostly focuses on heterogeneity based on demographic characteristics, thus broadening the scope of existing studies. Lastly, we offer several specific and actionable policy recommendations, providing a basis for decision-making to improve the mental health of the elderly in other developing countries.

The remainder of this paper is organized as follows: Section 2 reviews the relevant literature and proposes testable theoretical hypotheses. Section 3 discusses the empirical design, including data sources, econometric models, and variable definitions. Section 4 presents a series of empirical tests and provides an in-depth discussion of the results. Section 5 concludes with the findings, policy recommendations, and limitations.

2 Literature Review and Theoretical Hypotheses

2.1 Literature Review

2.1.1 The Impact of Internet Usage on the Mental Health of the Elderly

Internet usage significantly contributes to improving the mental health of the elderly. **Cotten et al. (2014)** found that internet usage significantly reduces the incidence of depression among retired

elderly in the United States, primarily by alleviating social isolation and feelings of loneliness. Similarly, research by **Zhou et al. (2024)** in China indicates that internet usage significantly enhances the mental health of the elderly by facilitating access to health information, promoting healthy lifestyles, and fostering social interactions. Longitudinal studies, such as that by **Yu et al. (2021)**, support these findings, demonstrating that internet usage notably reduces feelings of loneliness among the elderly and acts as a mediator by increasing social contacts. Further studies on the elderly in Japan by **Minagawa and Saito (2014)** corroborate these results, showing that information and communication technologies significantly reduce depressive symptoms by enhancing intergenerational relationships. **Li and Luo (2024)** emphasize the effectiveness of internet usage in health management and social entertainment, significantly enhancing the physical and mental health of the elderly. Additionally, **Feng et al. (2024)** highlight the crucial mediating role of social networks in the relationship between internet usage and depressive symptoms among the elderly, particularly noting a significant independent mediation effect in the urban elderly.

However, the impact of internet usage is not entirely positive. **Kraut et al. (1998)** found that excessive internet usage may reduce face-to-face interactions, leading to a smaller social circle and increased feelings of depression and loneliness. **Lam et al. (2020)** noted that different purposes of internet usage have varied effects on mental health; while information retrieval may lead to decreased life satisfaction, social networking can help reduce depression. **Francis et al. (2019)** also observed that the use of information and communication technologies enhances elderly happiness by fostering social connections, but caution is needed to avoid overreliance.

2.1.2 The Digital Divide and Mental Health

The negative impact of the digital divide on the mental health of the elderly has been substantiated in several studies. **Zhu (2023)** noted that the digital divide significantly undermines the psychological well-being of the elderly, making them more prone to depression. This phenomenon is particularly pronounced among the elderly with lower educational levels and those residing in rural areas. **Feng (2023)** emphasized that the development of a digital society has a significant impact on the health behaviors of the elderly. While digital technologies can improve both the physical and mental health of older adults, excessive digital engagement may also lead to negative consequences. **Zhang (2022)** further illustrated that internet usage mitigates depression symptoms among the middle-aged and elderly by promoting social participation, yet significant disparities exist between urban and rural areas, with rural elderly facing greater mental health challenges due to resource limitations. **Tang (2023)** found that mobile internet usage among rural elderly significantly enhances their physical and mental health, with varying impacts depending on different internet functionalities; social features notably improve mental health, while entertainment features should be used moderately. **Zhai et al. (2023)** also found that internet usage was low among Chinese elderly, but it helps reduce the risk of depression. **Li et al. (2018)** demonstrated that internet usage and social support exert significant inhibitory effects on depression among urban elderly, with internet usage playing a more pronounced role. These studies underscore the critical importance of bridging the digital divide in enhancing the psychological well-being of the elderly.

2.1.3 The Mediating and Moderating Mechanisms of Internet Usage

The impact mechanisms of internet usage on the mental health of the elderly are complex, involving various mediating and moderating factors. **Zhang et al. (2023)** analyzed the effects of internet access, digital literacy, and breadth of online participation on depression among the elderly. They found that digital integration significantly reduces depression among the elderly, with this effect being moderated by educational attainment and urban-rural differences. Based on social support theory, **Zhang (2021)** explored the relationship between internet usage, intergenerational support, and depression among the elderly and found that different types of intergenerational support had varied impacts on depression among the elderly, and that internet usage alleviated depression

among the elderly by promoting intergenerational support. **Yang et al. (2022)** further indicated that informal leisure activities facilitated by internet usage, such as socializing and entertainment, significantly benefit the mental health of the elderly. **Zhai (2021)** demonstrated that social participation among the elderly positively impacts their mental health, with internet usage facilitating social engagement and thereby improving psychological well-being. **Du (2022)** explored the effects of internet usage across different dimensions on depression among the middle-aged and elderly and found that varying internet usage frequencies and purposes lead to diverse impacts on mental health. High-frequency internet usage for social activities notably improves psychological health, whereas other purposes show less significant effects. These studies underscore that internet usage affects the mental health of the elderly through multiple mechanisms, highlighting that judicious internet usage can effectively enhance the psychological well-being of the elderly.

A review of the above literature reveals that, while existing studies provide a solid foundation for this paper, there are still areas for improvement. Firstly, existing research on this topic predominantly focuses on foreign contexts, with limited and inconsistent findings from domestic studies, underscoring the necessity for a systematic investigation in this paper. Secondly, current studies inadequately address endogeneity issues and often rely on cross-sectional data, which hinders rigorous causal identification. Thirdly, the underlying mechanisms and heterogeneous effects of internet usage on depression among the elderly are insufficiently explored in existing literature. In response, this paper aims to address these gaps by focusing on China as a developing country, utilizing longitudinal panel data from CHARLS, and employing a two-stage instrumental variable approach. It seeks to comprehensively uncover the long-term dynamic impacts of internet usage on elderly mental health, providing scientific evidence for policy-making and practice, thereby advancing research in elderly mental health.

2.2 Theoretical Hypotheses

2.2.1 Social Interaction Effect

Social networks refer to stable relationships formed through mutual connections among individuals and social members, encompassing both online and offline networks. Among these, family and friends networks constitute the most crucial offline social networks for the elderly. However, due to physical decline, generation gaps, and children moving away or being busy with work, the elderly find it challenging to maintain offline social networks. With the proliferation of the digital society, the internet provides a new social platform for the elderly, helping them engage in social interactions, learning, and shopping, thereby enhancing their connection with the outside world. As of June 2023, China had approximately 140 million internet users aged 60 and above, and this proportion continues to expand with increasing internet penetration. Internet usage not only alleviates loneliness among the elderly but also expands their social relationships, prevents social isolation, and increases interaction frequency with family and friends (**Chen, 2020**).

Enhanced social networks have a significantly positive impact on the psychological well-being of the elderly. Social interactions through the internet reduce feelings of loneliness and depression among the elderly (**Hu and Feng, 2022**). Social engagement enhances their sense of achievement, happiness, and security, serving as a crucial pillar for their integration into society and promotion of psychological health. The activity theory proposed by **Havighurst (1961)** suggests that the elderly can achieve self-awareness, bridge the gap with society, lessen loneliness, and attain higher life satisfaction through new social engagements. Increasing participation in both conventional and novel social activities is a valuable objective for improving the mental health of the increasingly aging population. The Social Convoy Theory also highlights the protective role of social relationship networks on psychological health (**Kahn and Antonucci, 1980**). Therefore, by strengthening family and friend networks, the internet alleviates loneliness among the elderly, promotes psychological health, and effectively reduces depression—a phenomenon termed here as the social interaction

effect. Based on this, the following hypothesis is proposed:

Hypothesis 1: Internet usage mitigates depression among the elderly through the social interaction effect.

2.2.2 Physical Exercise Effect

A series of studies have shown that internet usage among the elderly transcends temporal and geographical constraints, enhances interaction with sports service providers, and offers high-quality, convenient, and diverse sports services **(Lei, 2020; Lu, 2021)**. In the era of big data, the internet also accurately delivers nearby sports information and suitable sports equipment, thus lowering barriers for elderly participation in physical activities. The elderly who frequently use the internet engage in physical exercise and moderate to high-intensity activities more frequently each week. This suggests that the internet significantly boosts the elderly's enthusiasm for physical activity by providing convenience, scientific guidance, interactivity, and entertainment.

Increasing physical exercise has a significant positive impact on the psychological health of the elderly. Physical exercise can enhance cardiovascular function and physical fitness of the elderly, promote health, delay aging, reduce the incidence of age-related diseases, and improve sleep quality. Research indicates that physical activity enhances subjective well-being (**McAuley, 1994**), life satisfaction **(Schnohr et al., 2005**), effectively treats depression (**Martinsen, 1990**), and reduces anxiety (**Tate and Petruzzello, 1995**). Based on the active aging theory and health demand model, studies have found that regular physical exercise significantly increases the likelihood of social participation among the elderly (**Yang, 2021**). Moreover, physical exercise has strong antidepressant effects and greatly promotes mental health equity (**Fang and Guo, 2019**). This viewpoint has been widely acknowledged. Therefore, through increasing physical exercise, the elderly not only improve physical health but also significantly alleviate depression and enhance overall quality of life. We refer to this mechanism as the "physical exercise effect". Based on this, the following hypothesis is proposed:

Hypothesis 2: Internet usage alleviates depression among the elderly through the physical exercise effect.

2.2.3 Intergenerational Contact Effect

The current high population mobility in China often leaves adult children unable to care for their elderly parents due to work or study commitments, resulting in a shift in social roles and interpersonal relationships for the elderly upon retirement. This situation limits their access to information and deepens their sense of social isolation, impacting their psychological and mental health (**Cheng and Jiang, 2021**). The development of internet technology has provided convenient means for elderly individuals to stay in touch with their children, overcoming temporal and spatial barriers. This has significantly increased the frequency and quality of interactions between elderly parents and their children, thereby enhancing intergenerational support and subsequently improving the elderly's subjective well-being (**Hu and Feng, 2022**).

According to the social support buffering model and main effects model (**Uchino et al., 1996**), intergenerational support plays a crucial role in alleviating depression among the elderly. On the one hand, intergenerational support helps mitigate the impact of resource loss and buffers the effects of stress on the depression of the elderly (**Cong & Silverstein, 2008**). On the other hand, intergenerational support provides the elderly with positive social evaluations for effective parenting, directly reducing their depression (**Li et al., 2012**). The cognitive-behavioral theory of depression emphasizes that cognitive assessments are crucial variables influencing depression (**Dobson et al., 2014**). Intergenerational support meets the primary social goal of emotional management for the elderly and fosters a more positive attitude in cognitive assessments, effectively reducing depression among the elderly. We refer to this mechanism as the "intergenerational contact effect" and propose the following hypothesis based on this premise:

Hypothesis 3: Internet usage mitigates depression among the elderly through the intergenerational contact effect.

2.2.4 Educational Enhancement Effect

With the widespread adoption of the internet, an increasing number of elderly individuals are engaging in online education, learning new knowledge and skills through virtual courses. This allows them to find new joys and values in the learning process (**Xie and Chen, 2017**). The internet enables elderly individuals to access a broader range of information and knowledge, enhancing cognitive abilities and better adapting to social changes, thereby reducing feelings of loneliness caused by information isolation. In summary, the internet provides new learning opportunities for elderly individuals, expands their knowledge boundaries, and profoundly impacts their education.

Education can effectively mitigate the negative impact of age, gender, and family structure on the psychological health of elderly individuals (**Li and Chen, 2006**). As individuals age, their physical fitness gradually declines, but higher levels of education can help elderly individuals enhance their objective awareness of their health status, thereby influencing their psychological well-being. Studies indicate a positive correlation between cognitive function and life satisfaction among elderly individuals (**Jones, 2003**). Education enhances the self-awareness and self-care abilities of elderly individuals, reducing psychological issues, and providing social and recreational opportunities, thereby improving mental health and enhancing overall quality of life. We refer to this mechanism as the educational enhancement effect. Based on this, the following hypothesis is proposed:

Hypothesis 4: Internet usage alleviates depression among elderly individuals through the educational enhancement effect.

3 Empirical design

3.1 Data sources

The data for this study primarily come from the China Health and Retirement Longitudinal Study (CHARLS). CHARLS is a large-scale, interdisciplinary survey project led by the National School of Development at Peking University, jointly executed by the China Social Science Survey Center and the Youth League Committee of Peking University. The survey aims to collect household and individual data from Chinese adults aged 45 and above. CHARLS employs a Probability Proportional to Size (PPS) sampling method, selecting samples sequentially from counties to villages, residential areas, households, and individuals. The national baseline survey was conducted in 2011, covering 150 counties (districts), 450 villages (residential areas), 10,257 households, and 17,708 individuals, thereby providing a comprehensive representation of China's middle-aged and elderly population. The CHARLS questionnaire includes demographic information, family structure, work and retirement details, health status, and health-related behaviors. Since 2011, national surveys have been conducted biennially, resulting in five rounds of data spanning from 2011 to 2020. As of now, CHARLS stands as the most authoritative and largest representative database for studying the health of elderly individuals in China.

The data cleaning process proceeded as follows: (1) The data from the five survey rounds were matched and merged, resulting in a total of 96,616 observations. (2) Missing values for the key explanatory and dependent variables were removed, totaling 15,735 (96,616 - 80,881). (3) Further removal of missing values for control variables amounted to 1,179 (80,881 - 79,702). (4) Subsequently, 2,826 singleton group values were removed (79,702 - 76,876). This resulted in a final sample of 76,876 observations for use in the regression analysis.

3.2 Econometric Specification

To address potential endogeneity issues, this study constructs a two-stage instrumental variables model based on bidirectional fixed effects:

$$\widehat{Internet}_{it} = \beta_0 + \beta_1 NBDCPZ_{it} + X`\theta + \sigma_i + \gamma_t \quad (1)$$

$$LnDepress_{it} = \alpha_0 + \alpha_1 \widehat{Internet}_{it} + X`\theta + \sigma_i + \gamma_t + \varepsilon_{it} \quad (2)$$

Equation (1) represents the first-stage regression, where $\widehat{Internet}_{it}$ denotes the fitted values of internet usage; $NBDCPZ_{it}$ represents the dummy variable for National Big Data Comprehensive Pilot Zones; $X`\theta$ denotes a series of control variables; σ_i represents individual fixed effects to control for individual differences; γ_t represents time fixed effects to control for unobserved shocks across different years. Controlling for both time-fixed and individual-fixed effects aims to further eliminate endogeneity issues caused by omitted variables. The essence of the first-stage regression lies in regressing the endogenous variable $Internet_{it}$ on exogenous variables to obtain the fitted values $\widehat{Internet}_{it}$. Equation (2) represents the second-stage regression, where $LnDepress_{it}$ denotes depression among the elderly, ε_{it} represents the error term, with other variables as in Equation (1). The essence of the second-stage regression lies in regressing $Lndepress_{it}$ on the instrumented $\widehat{Internet}_{it}$ to obtain accurate estimates of the coefficient α_1.

3.3 Definition of Main variables

Depression (LnDepress). The level of depression among the elderly was assessed using the widely recognized 10-item Center for Epidemiologic Studies Depression Scale (CESD-10). This scale consists of 10 items, each rated on a 4-point Likert scale ranging from 1 to 4, with items 5 and 8 reverse scored. The total score, derived by summing the individual item scores, reflects the level of depression, with higher scores indicating a greater risk of depression. To mitigate the impact of extreme values and facilitate the interpretation of results, the total depression score was logarithmically transformed.

Internet Usage (Internet). Internet usage was assessed by asking respondents in the CHARLS survey, “Have you used the internet in the past month?” Responses were coded as 1 for “yes” and 0 for “no.” This core explanatory variable exhibits significant potential endogeneity issues with depression; higher levels of depression among the elderly may inversely affect their internet usage behavior, potentially compromising the credibility of regression results.

Instrumental Variable (NBDCPZ). On March 1, 2016, China’s first National Big Data Comprehensive Pilot Zone (Guizhou) received official approval from the National Development and Reform Commission, the Ministry of Industry and Information Technology, and the Cyberspace Administration of China. This pilot zone aims to conduct systematic trials in areas such as data resource management and sharing, data center integration, and data resource application. The plan is to develop a series of advanced big data products and cultivate key big data enterprises over three to five years, thereby promoting economic transformation and upgrading.

On October 8, 2016, these authorities issued another notice approving the establishment of additional National Big Data Comprehensive Pilot Zones in seven regions, including Beijing-Tianjin-Hebei. These newly approved national-level pilot zones comprise two inter-regional comprehensive pilot zones (Beijing-Tianjin-Hebei and the Pearl River Delta), four regional demonstration pilot zones (Shanghai, Henan, Chongqing, and Shenyang), and one pilot zone focused on the coordinated development of big data infrastructure (Inner Mongolia). The construction of these zones will facilitate trials and exploration in areas such as big data policy innovation, public data openness and sharing, big data innovation applications, big data industry clustering, big data element circulation, data center integration and utilization, and international cooperation in big data, thereby driving the innovative development of big data in China.

In this study, we creatively use the NBDCPZ (National Big Data Comprehensive Pilot Zone) as

an instrumental variable for elderly internet usage. This approach effectively addresses potential endogeneity issues, thereby enhancing the credibility of the regression results.

Control Variables. Following the approaches of **Zhu et al. (2023), Li and Luo (2024), Zhang et al. (2023), and Yang et al. (2022)**, the selected control variables include: Gender, Age, Household Registration (HR), Marital Status (MS), Education, Self-rated Health (SH), Medical Insurance (MI), Personal Income (PI), and Alcohol Consumption (AC).

3.4 Descriptive statistics

Table 1 presents the main variables and their descriptive statistics as follows: the mean score for depression (LnDepress) is 2.847; the mean for Internet usage (Internet) is 0.149, indicating that 14.9% of the sample has used the Internet; and the mean for NBDCPZ is 0.1, suggesting that 10% of observations are from the National Big Data Comprehensive Pilot Zone. Details for other variables are omitted for brevity.

Table 1. Definition and description of main variables

Variable	Obs	Mean	Std. Dev.	Definition
LnDepress	79702	2.847	0.332	Using the CESD-10 scale, scores were summed and logged.
Internet	79702	0.149	0.356	Respondents were asked whether they used the internet in the past month, with responses coded as 1 for “yes” and 0 for “no”.
NBDCPZ	79702	0.1	0.3	If located in a pilot area, assign a value of 1 to years after the pilot period; otherwise, assign a value of 0.
Gender	79702	1.521	0.5	Male=1, Female=2.
Age	79702	60.296	9.731	Current year - year of birth. Due to the presence of outliers, perform a 1% truncation of the upper and lower ends.
HR	79702	0.45	0.497	Rural household registration=1, others=0.
MS	79702	0.88	0.325	Married=1, others=0.
Education	79702	2.398	4.116	Not completed primary school = 0, Primary school = 6, Junior high school = 9, Senior high school/Technical school = 12, Junior college = 15, Bachelor's degree = 16, Master’s degree = 19, Doctorate = 22.
SH	79702	2.78	0.933	Very poor=1, poor=2, fair=3, good=4, very good=5, excellent=6.
MI	79702	0.95	0.219	With medical insurance = 1, Other = 0.
PI	79702	0.231	0.421	Received wages or bonuses in the past year = 1, Other = 0.
AC	79702	2.375	0.88	In the past month, drank alcohol more than once = 1, less than once = 2, did not drink = 3.

Note: It should be noted that in this table, the number of observations for variables is higher than in the regression tables. This discrepancy is due to the removal of some singleton groups during the regression process. This deletion was automatic and did not substantively affect the conclusions of this study.

4 Results and Discussion

4.1 Benchmark regression

To present comparative results, Columns (1)-(2) in Table 2 show the results of Ordinary Least Squares (OLS) regressions: Column (1) indicates that the coefficient of Internet usage (Internet) on depression (LnDepress) is -0.0483, significant at the 1% level. Column (2) presents the regression

results further controlling for both individual fixed effects (Individual FE) and year fixed effects (Year FE); the coefficient of Internet usage (Internet) is -0.0151, still significant at the 1% level. Table 2, Columns (3)-(4), present the results of the Two-Stage Instrumental Variable Method (IV): Column (3) shows that the coefficient of Internet usage (Internet) on depression (LnDepress) is -0.0016, significant at the 1% level, with KP-LM and CD-Wald tests confirming the validity of the instruments. Column (4) presents the regression results further controlling for Individual FE and Year FE; the coefficient of Internet usage (Internet) is -0.0141, and the instruments remain valid.

The baseline regression results indicate the following: First, the coefficient significantly decreases after using IV regression, suggesting that the OLS regression overestimated the impact of Internet usage on depression. Second, Column (4), which simultaneously controls for both individual fixed effects and year fixed effects, further mitigates endogeneity issues due to omitted variables. Therefore, Column (4) is used as the baseline regression in this study, showing that Internet usage significantly reduces depression scores by 1.41%. This finding indicates a significant alleviation of depression among the elderly, consistent with the theoretical hypothesis.

Column (4) also reports the impacts of other control variables: Education significantly reduces LnDepress, indicating that higher education levels ease depression. SH significantly reduces LnDepress, suggesting that better self-rated health decreases the likelihood of depression. MI significantly promotes LnDepress, implying that medical insurance does not alleviate depression. AC significantly reduces LnDepress, indicating that alcohol consumption is beneficial in alleviating depression. The other variables Gender, Age, HR, MS, and PI do not show significant effects in the baseline regression. It is important to note that the reported R-squared in the IV regression process has no practical significance; hence, it is not reported in this study.[1]

Table 2. Benchmark regression

VARIABLES	LnDepress			
	OLS	OLS-FE	IV	IV-FE
	(1)	(2)	(3)	(4)
Internet	-0.0483***	-0.0151***	-0.00160***	-0.0141***
	(0.00308)	(0.00373)	(0.000209)	(0.00350)
Gender	0.0745***	0.00492	0.000754***	0.000501
	(0.00256)	(0.0244)	(2.59e-05)	(0.000398)
Age	0.000898***	0.00380	3.61e-06**	-0.000119
	(0.000126)	(0.00426)	(1.53e-06)	(8.97e-05)
HR	0.0803***	0.00178	0.000779***	0.000114
	(0.00228)	(0.00369)	(2.36e-05)	(8.08e-05)
MS	-0.0780***	-0.0595***	-0.000775***	0.000146
	(0.00369)	(0.00742)	(3.71e-05)	(0.000225)
Education	-0.00563***	-0.00101***	-5.66e-05***	-7.91e-05***
	(0.000272)	(0.000322)	(2.75e-06)	(1.85e-05)
SH	-0.0897***	-0.0257***	-0.000867***	-0.000271***
	(0.00123)	(0.00122)	(1.35e-05)	(2.35e-05)
MI	-0.0126**	-0.00371	-8.55e-05*	0.000173*
	(0.00507)	(0.00490)	(5.15e-05)	(0.000101)
PI	-0.0470***	-0.0178***	-0.000336***	6.13e-05
	(0.00277)	(0.00317)	(3.87e-05)	(8.69e-05)
AC	0.00788***	0.00465**	5.29e-05***	-0.000224***
	(0.00140)	(0.00198)	(1.50e-05)	(7.79e-05)
KP-LM	N	N	1073.066	20.724
CD-Wald	N	N	2000.060	26.327

[1] https://www.stata.com/support/faqs/statistics/two-stage-least-squares/

Year FE	N	Y	N	Y
Individual FE	N	Y	N	Y
Robust	Y	Y	Y	Y
Observations	79,702	79,702	79,702	76,876
R-squared	0.127	0.023	N	N

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; KP-LM represents Kleibergen-Paap rk LM statistic, testing the relevance of IV; CD-Wald represents Cragg-Donald Wald F statistic, testing the weak relevance of IV; Year FE denotes time fixed effects, controlling for unobserved shocks across different years; Individual FE denotes individual fixed effects, controlling for heterogeneity across individuals; Robust indicates the use of robust standard errors, addressing heteroskedasticity effects.

4.2 Robustness checks

To examine the robustness of the baseline regression results, this section conducts a series of robustness tests, as detailed in Table 3: Column (1) transforms the depression variable into a binary outcome, following the approach of Li and Luo (2024), where depression scores exceeding 10 are assigned a value of 1, and 0 otherwise. Using the IV method based on a Probit model, the results indicate a significant reduction in depression due to internet usage (the coefficient is -2.116 and statistically significant at the 1% level), confirming robustness. Column (2) re-estimates the regression using internet usage frequency instead of binary internet usage. Frequency categories—almost daily=3, almost every week=2, not regularly=1—are derived directly from the CHARLS questionnaire. The results show a significant decrease in depression by 2.01%, reaffirming robustness. Column (3) replaces the IV method with Propensity Score Matching (PSM) to address potential selection bias in internet usage, where the choice of using the internet may be influenced by other factors, leading to biased regression coefficients. Using a 1:1 nearest-neighbor matching, the results indicate a significant reduction in depression by 0.0761%, demonstrating robust results. Column (4) utilizes a smart city pilot virtual variable as a new instrumental variable for the re-estimation. The results show a significant reduction in depression by 1.35%, confirming robustness.

Table 3. Robustness regression

	LnDepress			
VARIABLES	Probit Model	Frequency	PSM	Smart City
	(1)	(2)	(3)	(4)
Internet	-2.116***	-0.0201***	-0.000761***	-0.0135***
	(0.530)	(0.00111)	(0.0000877)	(0.00520)
Controls	Y	Y	Y	Y
KP-LM	N	182.559	N	6.757
CD-Wald	N	304.661	N	5.604
Year FE	Y	Y	Y	Y
Individual FE	Y	Y	N	Y
Robust	Y	Y	Y	Y
Observations	88,359	2,691	79,702	76,876
R-squared	N	N	0.348	N

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; Controls represent a series of control variables; KP-LM represents the Kleibergen-Paap rk LM statistic, testing the relevance of the instrumental variables (IV); CD-Wald represents the Cragg-Donald Wald F statistic, testing the weak relevance of the IV; Year FE denotes time fixed effects, controlling for unobservable shocks across different years; Individual FE denotes individual fixed effects, controlling for heterogeneity across individuals; Robust denotes the use of robust standard errors, addressing heteroskedasticity issues.

4.3 Mechanism explorations

The empirical results above clearly demonstrate that internet usage significantly reduces depression levels among the elderly. Moreover, the theoretical hypotheses proposed above have anticipated potential mechanisms. This section will therefore conduct mechanism tests to validate these theoretical hypotheses. Detailed results are provided in Table 4 below.

Social Interaction Effect (SIE). Regarding social interactions, the following activities were quantified: visiting friends in the past week; playing mahjong, chess, cards, or visiting community activity rooms; providing assistance to non-cohabitating relatives, friends, or neighbors; engaging in activities such as dancing, fitness, or qigong with clubs or organizations; volunteering or participating in charitable activities; and caring for non-cohabitating patients or disabled individuals. The total frequency of these activities was aggregated and log-transformed in this study. Column (1) indicates that internet usage increases the frequency of elderly social interactions by 49.2%, confirming the Social Interaction Effect.

Physical Exercise Effect (PEE). Regarding physical exercise, the following activities were quantified: the number of days per week engaging in vigorous, moderate, or light physical activities for more than 10 minutes. The total frequency of these activities was aggregated and log-transformed in this study. Column (2) indicates that internet usage increases the frequency of elderly physical exercise by 68%, confirming the Physical Exercise Effect.

Intergenerational Contact Effect (ICE). Regarding intergenerational contact, activities include: contacting all children via phone, message, WeChat, mail, or email, and assigning reverse scores based on the frequency of these contacts as follows: Almost every day=10, 2-3 times a week=9, Once a week=8, Every two weeks=7, Once a month=6, Once every three months=5, Once every six months=4, Once a year=3, Almost never=2, Other=1. The total scores of these frequencies were aggregated and log-transformed in this study. Column (3) indicates that internet usage increases the intergenerational contact scores of the elderly by 37.4%, confirming the Intergenerational Contact Effect.

Educational Enhancement Effect (EEE). Regarding educational enhancement, the following activity was quantified: whether the individual attended school or training courses in the past month. Clearly, this is a binary variable and should be regressed using the two-stage instrumental variable method based on the Probit model. Column (4) demonstrates that internet usage significantly increases the likelihood of the elderly receiving education, confirming the Educational Enhancement Effect.

Table 4. Mechanism test

VARIABLES	SIE	PEE	ICE	EEE
	(1)	(2)	(3)	(4)
Internet	0.492**	0.680**	0.374**	2.183***
	(0.244)	(0.291)	(0.151)	(0.260)
Controls	Y	Y	Y	Y
KP-LM	6.943	22.750	9.698	N
CD-Wald	8.832	24.261	10.196	N
Year FE	Y	Y	Y	Y
Individual FE	Y	Y	Y	N
Robust	Y	Y	Y	Y
Observations	38,860	47,905	30,362	38,985
R-squared	N	N	N	N

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; Controls represent a series of control variables; KP-LM denotes the Kleibergen-Paap rk LM statistic, testing the relevance of the instrumental variables (IV); CD-Wald represents the Cragg-Donald Wald F statistic, testing the weak relevance of the IV; Year FE denotes time fixed

effects, controlling for unobservable shocks across different years; Individual FE represents individual fixed effects, controlling for heterogeneity across individuals; Robust indicates the use of robust standard errors, controlling for heteroskedasticity effects.

4.4 Heterogeneity analyses

To further enrich the understanding of the relationship between internet usage and depression, this study conducted a series of heterogeneity analyses, as shown in Table 5.

Comparison of Urban and Rural Areas: Urbanization exacerbates the hollowing-out problem in rural areas, leading to higher levels of loneliness and more severe depression among the rural elderly (**Liu et al., 2020**). The cumulative disadvantage hypothesis suggests that this urban-rural depression disparity stems from the urban-rural divide, where rural residents accumulate disadvantages that peak in old age (**Danaher, 2003**). The diffusion of the internet has varying effects on alleviating depression among the elderly in urban and rural areas. Due to better infrastructure, the urban elderly benefit more from internet access, facilitating easier social participation, information access, and entertainment, thereby effectively reducing feelings of loneliness and depression (**Lei, 2020**). Moreover, proximity to children's residences and stable family support systems in urban areas, coupled with internet usage, further alleviates their depression (**Carstensen, 1999**). In contrast, the rural elderly face limited internet access due to inadequate infrastructure, resulting in fewer opportunities to utilize internet benefits for social interaction and support. Combined with a lack of effective family support systems and communication channels, the internet's impact in alleviating depression among the rural elderly is less pronounced compared to their urban counterparts. Therefore, it is expected that the alleviating effect of internet usage on depression would be more significant in urban areas. The grouped regressions in columns (1)-(2) confirm this hypothesis, indicating that the alleviating effect of internet usage is higher in urban areas (-1.74%) compared to rural areas (-0.774%).

Comparison of Eastern and Non-Eastern Regions. In eastern China, the elderly have more opportunities to engage in social activities, access health information, and participate in online entertainment through the internet, resulting in a more pronounced alleviation of depression **(Yang et al., 2021)**. Furthermore, the higher economic development in eastern regions generally correlates with higher levels of education and economic capability among the elderly, facilitating easier access to and utilization of the internet for psychological well-being **(Zhang et al., 2021)**. In contrast, the elderly in non-eastern regions experience lower internet usage rates and breadth due to limited internet resources, technological barriers, and economic constraints, leading to less significant alleviation of depression compared to their counterparts in eastern regions **(Xie et al., 2021)**. Therefore, it is anticipated that the therapeutic effect of internet usage on elderly depression is more pronounced in eastern China and remains limited in non-eastern regions. According to the classification standards of the National Bureau of Statistics, eastern China includes the provinces (and cities) of Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan. The grouped regressions in columns (3)-(4) confirm this hypothesis, indicating that the alleviating effect of internet usage is higher in eastern regions (-1.85%) compared to non-eastern regions (0.00196, which is statistically insignificant).

Comparison of Broadband China Pilot and Non-Pilot Areas. Since its implementation in 2013, the "Broadband China" strategy has significantly enhanced broadband network coverage and accessibility through advanced network technologies and infrastructure development. In pilot areas, the elderly have more frequently utilized the internet for social interactions and access to health information, resulting in a notable reduction in depression. In contrast, non-pilot areas, constrained by limited internet resources and technical support, offer fewer opportunities for elderly internet usage, leading to less significant alleviation of depression compared to pilot areas **(Liao et al., 2020)**. Moreover, the widespread availability of broadband networks has facilitated increased elderly participation in social activities and access to more health services, further mitigating depression (**Du**

et al., 2023). Therefore, this study anticipates that the therapeutic effect of internet usage is greater in the pilot areas of Broadband China and smaller in the non-pilot areas. The grouped regressions in columns (5)-(6) confirm this hypothesis, indicating that the alleviating effect of internet usage is higher in pilot areas (-1.9%) compared to non-pilot areas (-0.000707, which is statistically insignificant).

Table 5. Heterogeneity regression

	LnDepress					
VARIABLES	Urban	Village	Eastern	Non-Eastern	Pilot	Non-Pilot
	(1)	(2)	(3)	(4)	(5)	(6)
Internet	-0.0174***	-0.00774***	-0.0185***	0.00196	-0.0190*	-0.000707
	(0.00296)	(0.00220)	(0.00542)	(0.00267)	(0.0102)	(0.00393)
Controls	Y	Y	Y	Y	Y	Y
KP-LM	9.438	21.456	13.549	10.199	3.786	4.446
CD-Wald	10.549	39.755	17.314	12.886	3.903	6.327
Year FE	Y	Y	Y	Y	Y	Y
Individual FE	Y	Y	N	Y	Y	Y
Robust	Y	Y	Y	Y	Y	Y
Observations	20,514	30,083	23,822	53,054	14,082	53,613
R-squared	N	N	N	N	N	N

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; Controls represent a series of control variables; KP-LM stands for Kleibergen-Paap rk LM statistic, testing the relevance of IV; CD-Wald represents Cragg-Donald Wald F statistic, testing the weak relevance of IV; Year FE denotes time fixed effects, controlling for unobservable shocks across different years; Individual FE represents individual fixed effects, controlling for heterogeneity across individuals; Robust indicates the use of robust standard errors, mitigating the impact of heteroskedasticity.

5 Conclusions

This paper constructs a theoretical framework to analyze the relationship between internet usage and elderly depression, proposing testable hypotheses and employing a two-stage IV approach. The empirical results indicate that internet usage significantly reduces elderly depression levels by 1.41%. Specifically, internet usage functions through four primary mechanisms: the social interaction effect, physical exercise effect, intergenerational contact effect, and educational enhancement effect. Further heterogeneity analysis reveals that the alleviating effect of internet usage on depression is particularly significant in urban areas, eastern regions, and broadband pilot areas in China. These findings provide empirical evidence from a developing country to improve elderly mental health and offer strong policy implications, emphasizing the importance of promoting internet usage and digital education across various regions to comprehensively enhance the psychological well-being of the elderly.

Based on the findings of this study, we propose three feasible policy recommendations: (1) Promote the development of internet infrastructure in rural and non-Eastern regions: The study finds that while internet usage significantly reduces depression among the elderly, limited internet resources in these areas restrict their access. The government should establish special funding

programs and public internet access points in each county and city. Collaboration with telecommunications companies should be encouraged to facilitate internet coverage projects, ensuring planned implementation and conducting regular progress evaluations. (2) Implement digital literacy education and training programs specifically for the elderly: Internet usage notably alleviates elderly depression by improving social interactions, promoting physical exercise, and enhancing intergenerational connections. Governments should establish dedicated digital literacy education programs, utilizing community resources and volunteer networks to form digital education volunteer teams, ensuring personalized learning support for the elderly. (3) Develop an internet-based mental health support platform: Empirical results indicate that internet usage significantly enhances the mental health of the elderly, particularly in the eastern and broadband pilot areas of China. The government should create an internet platform specifically designed to support the psychological health of the elderly. Promotion of this platform should be carried out through channels such as television, radio, and community outreach to ensure elderly awareness and accessibility.

This study has two primary limitations: (1) Sample selection bias: The data used in this study are derived from CHARLS, which covers a wide range of middle-aged and elderly populations in China. However, there may still be sample selection bias because certain specific groups, such as those residing in remote areas or elderly individuals not participating in the survey, may not have been included, thus affecting the generalizability of the results. (2) Operational mechanisms: While this study explores various mechanisms through which internet usage affects elderly depression, further research is needed to investigate the specific operational mechanisms and their relative importance in greater detail.

In conclusion, this study provides valuable insights into the positive impact of internet usage on alleviating depression among the elderly in developing countries. The findings underscore the necessity of targeted policy interventions to enhance digital inclusion and mental health support for the elderly, ultimately contributing to their overall well-being.

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