Information Research - Vol. 30 No. 1 (2025)

When aging meets digitisation: can urban digital technology innovations enhance the well-being of older adults?

Yajing Wu and Xianglei Zhu
DOI: https://doi.org/10.47989/ir30140525

Abstract

Introduction. With the rapid advancement of urban digital transformation in China, the significance of innovation in urban digital technology has become increasingly pronounced in the lives of elderly individuals. However, existing research on its impact remains limited. This study investigates the profound influence of urban digital technology innovation on the well-being of elderly people in Chinese cities, elucidating key mechanisms and moderating factors.

Method. This study collected data on 1,317,694 digital technology innovation patents in urban areas, the level of urban digital transformation, and factors such as social support and well-being among elderly residents in Chinese cities. Empirical analysis was conducted using an OLS mixed-effects model, yielding compelling and convincing results.

Results. Urban digital technology innovation significantly and positively affects the well-being of elderly individuals. The widespread adoption of digital technology broadens the horizons of the elderly, providing increased opportunities for social interaction, knowledge acquisition and health management. Furthermore, we identify urban digital transformation as a mediating factor between urban digital technology innovation and the well-being of elderly individuals. Crucial elements in this mediation encompass the establishment of a digital society, efficient digital governance, and robust digital infrastructure. Intriguingly, social support, serving as a moderating variable, influences the extent to which urban digital technology innovation affects the well-being of elderly individuals.

Conclusion. Our study highlights the crucial role of urban digital innovation in enhancing elderly well-being. It offers valuable insights for policymakers to promote digital inclusion, social support, and sustainable urban development strategies that benefit older adults.

Introduction

The concept of "Digital China" stands as a cornerstone in China's quest for a unique path to modernisation in the digital era, providing strong support for establishing new national competitive advantages (Wang, 2023). This ambition propels cities across the nation to engage actively in digital technology innovation, striving to weave digital technology into the fabric of human economy, politics, culture, society, and ecological civilisation (Wang et al., 2021; Zhang et al., 2021). Such efforts play a vital role in driving urban digital transformation, fostering social development, and spurring economic growth, marking a fundamental shift in lifestyles and social structures (Zhuo & Chen, 2023). Amidst this transformation, the elderly population emerges as a critical demographic, with China's seventh national population census highlighting the growing number of individuals aged 60 and above reaching 264 million, or 18.7% of the total population. This figure is expected to soar beyond 300 million by 2025, indicating a transition towards a moderately aging society (Duan et al., 2022). The challenge of integrating the elderly into the rapidly evolving urban digital landscape, therefore, becomes a pressing concern, raising questions about how to enhance their quality of life in the face of such changes.

The penetration of urban digital technologies into daily life has seen the elderly population gradually embracing these tools, thereby participating more actively in the digital world (Barnard et al., 2013). However, this trend sparks a debate on the actual impact of urban digital technology on the well-being of older adults. Some scholars argue that digital technologies afford the elderly greater opportunities for social interaction, access to information, health management and community engagement (LaMonica, 2021), alongside providing vital support in healthcare and elderly care (Davern, 2020; Zhang & Cheng, 2021). These advancements purportedly improve their life quality and convenience significantly. Conversely, others point to the challenges posed by rapid technological advances, such as the emergence of a digital divide (Lythreatis, 2022; Wang & Wu, 2021), technological barriers (Xie et al., 2020) and increased social isolation (Barbosa, 2019), which could adversely affect the elderly's well-being in the digital age. Moreover, the digital development of Chinese cities, characterised by advancements in urban digital society, economy and government, is believed to play a crucial role in shaping the well-being of older adults (Ciasullo et al., 2020; Marshall, 2020; Panagiotopoulos, 2019). The extent to which social support can mediate the relationship between digital technology innovation and the well-being of the elderly remains an area ripe for exploration (Choudrie et al., 2020; Kamin, 2020; Li et al., 2022).

This study explores the impact of urban digital technology on the well-being of China's elderly, with a focus on the mediating effects of digital development (including society, government, and infrastructure) and the moderating role of social support. It aims to bridge a significant gap by examining the interplay between digital innovation and social support in enhancing elderly well-being. Through detailed analysis, the research offers empirical insights for policymakers and practitioners to improve elderly integration and quality of life in the digital era. The findings highlight how digital transformation and social support together influence elderly well-being, providing new theoretical perspectives and practical guidance for boosting digital engagement among the elderly. This contributes to the broader discourse on aging societies and urban digitalization, presenting strategies for leveraging digital technology and social support to enhance the lives of older adults.

The structure of this article is as follows: the second section is a literature review to summarise prior research findings on the relationship between digital technology innovation and the well-being of older individuals. We will also explore the theoretical foundation for intermediary variables such as urban digital society, digital government and digital infrastructure indicators, as well as social support as a moderating variable. In the third section, we will introduce the research methodology, including research design, data collection, sample selection, variable measurement and data analysis methods. The fourth part will present the research results, including descriptive

statistical analysis, correlation analysis, mediation effect analysis and moderating effect analysis. Finally, in the fifth section, we will discuss the interpretation and significance of the findings, identify the limitations of the study and ultimately summarise the conclusions.

Review and theoretical assumptions

The relationship between digital technology innovation and the well-being of urban elderly

How to effectively harness the benefits of digital technology innovation to serve the elderly population in urban areas, providing more convenient, secure and reliable digital services and support, has become one of the goals pursued by cities across China. With the rapid development of digital technology innovation in Chinese cities, the application of digital technology may have a meaningful impact on the well-being of urban elderly individuals, a vulnerable group (Zhang et al., 2021). Some scholars have argued that the digital divide, technological barriers, and information overload generated during the development of digital technological innovations may lead to difficulties in the application of digital technology for some older adults, thus reducing their sense of well-being. For example, Choudrie (2020) conducted a survey on the usage and adoption of digital products among older people in the UK and found that the elderly are prevalent, and factors such as age and physical condition can affect the well-being of elderly individuals when using digital products.

Other scholars believe that digital technological innovation has brought more convenience and opportunities for social participation to urban elderly individuals, thus improving their sense of well-being (Castellacci & Tveito, 2018). Scholars such as Oderanti (2021) and Zhao (2022) argued that through digital technological innovation, elderly individuals can access medical and health information, community services and cultural and entertainment content, realising the rapid transmission and exchange of information to meet various daily life needs. Czaja (2016) and Sun (2020) found that digital health monitoring systems and telemedicine services make it more convenient for the elderly to manage health issues and alleviate the troubles caused by illnesses. In addition, the innovative development of digital technology provides elderly individuals with more channels to connect with family and friends. Tools such as social media and video calls have facilitated communication between older adults and their family and friends, alleviating loneliness and emotional isolation due to spatial distance and enhancing their social support systems. These positive factors help to enhance the sense of well-being and life satisfaction of the elderly. In the process of urban digital technology innovation development, it is necessary to prioritise the cultivation of digital skills and digital literacy among elderly individuals, ensuring that they can fully participate in the digital life and better enjoy the convenience and benefits brought by digital technology innovation, and thus enhance their sense of well-being of the elderly. Therefore, this study proposes the following hypothesis:

H1: The level of urban digital technological innovation positively affects the well-being of urban elderly individuals.

The mediating role of digital transformation in cities

Urban smart upgrades and digital transformation play an essential role in addressing the demands of rapid urban development, improving quality and efficiency of urban management, and fostering industrial growth (Zhao & Zhang, 2020). These have evolved into enduring developmental imperatives for cities. With the continuous development and application of digital technology, urban digital transformation has emerged as an important strategy for advancing urban development and social governance (Yigitcanlar et al., 2020). Digital technology innovations encompass cutting-edge technologies such as artificial intelligence, big data, and the Internet of Things (Gupta, 2023). The application of these technologies in cities has not only changed the way of urban operation but, more importantly, provided elderly individuals with smarter and more

convenient services (Mozumder, 2023), thus laying the foundation for improving the well-being of the elderly. For example, digital healthcare systems enable elderly individuals to receive healthcare services at home (Perdana & Mokhtar, 2022).

Urban digital technology innovation affects multiple aspects of urban digital transformation, including digital society, digital government, and digital infrastructure (Calvo, 2020; Komninos et al., 2020). The construction of a digital society is an essential part of comprehensive digital transformation and serves as a crucial lever for advancing urban high-quality development, creating a high-quality life and achieving efficient governance. Innovative applications of digital technology bring city residents closer together, fostering social interaction and information sharing, while also expanding the social circles of elderly individuals (Rozzano et al., 2021). Through digital social platforms, elderly individuals can stay connected with family, friends and the community, alleviating feelings of social isolation, enhancing their sense of belonging, and contributing to an increased sense of well-being (Cotten, 2022). Digital government is a key facet of accelerating the construction of Digital China in the new era, and digital governance is an inevitable requirement to promote the modernisation of the national governance system and governance capacity (Zhou, 2023). Digital technology provides more scientific and efficient means for urban governance, promoting interaction and participation between the government and citizens (Castelnovo et al., 2016). As part of the urban population, elderly individuals can access government services and policy information more conveniently, increasing their sense of participation in urban governance and subsequently enhancing their sense of well-being. Digital infrastructure refers to the foundational facilities that support digital applications and information transmission. Digital technology innovations have improved urban infrastructure, such as transportation, communication, and energy (Zhou, 2023). Elderly individuals can use urban transportation and infrastructure more conveniently through digital technology, thereby improving their quality of life. Smart city facilities and digital healthcare systems provide more convenient living conditions for the elderly (Castelnovo et al., 2016; Cotten, 2022), reducing their burden and increasing their life satisfaction.

The digital transformation of cities creates more welcoming, intelligent, and accessible urban environments for elderly individuals, providing more significant opportunities for social interaction and services while enpowering them to make independent choices and integrate into society more effectively. These factors collectively contribute to enhancing the well-being of elderly individuals in digitally transformed cities. Therefore, this study proposes the following hypotheses:

H2: Urban digital transformation mediates the relationship between urban digital technology innovation and the well-being of older adults.

H2a: The digital society component within the digital transformation of cities mediates the relationship between digital technological innovation and the well-being of older people.

H2b: Digital government within the digital transformation of cities mediates the relationship between digital technological innovation and the well-being of older people.

H2c: Digital infrastructure within the digital transformation of cities mediates the relationship between digital technology innovation and the well-being of older people.

The moderating role of social support

Urban digital technology innovations offer elderly individuals increased convenience and opportunities for social participation, including intelligent healthcare services and digital social platforms (Davern, 2020; Zhang et al., 2021). Nevertheless, older adults may encounter difficulties and challenges when navigating these new digital services and technologies. Social support theory suggests that individuals can improve their well-being and psychological health by obtaining

substantial support, emotional understanding and care from others when dealing with stress, challenges, or difficulties (Deichert, 2021; Gan et al., 2020; Mensah, 2021). As a crucial psychological and social resource, social support can assist older adults in better adapting to the changes brought about by urban digital technological innovations, enhance their positive coping abilities and augment their sense of well-being. Social support can emanate from various sources, such as family, friends, communities and voluntary organisations (Alsubaie, 2019), offering emotional support, practical assistance and informational guidance to older adults, enabling them to surmount barriers in utilising digital technologies and elevating their acceptance and adaptability to digital transformation.

First, social support can alleviate anxiety and resistance among older adults towards digital technology innovation (Papa et al., 2016). When confronted with new digital services and technologies, older adults may experience discomfort and concerns, but receiving support and understanding from family, friends, or communities (Perdana & Mokhtar, 2022) can mitigate their resistance to digital technologies and increase their acceptance of new technologies. Second, social support offers substantial assistance to older individuals in their digital transformation (Cross & Milstein, 2022). Family members or voluntary organisations can aid elderly individuals in learning and use digital technologies, resolving issues they encounter, and bolstering their self-confidence and proficiency, thus enhancing their overall well-being. In addition, social support provides elderly individuals with increased opportunities for socialisation and engagement in digital platforms (Grossman et al., 2000). Through social support, elderly individuals can more easily participate in digital social networks, engage in digital community activities, expand their social circles, and fortify their sense of social support and well-being (Liu et al, 2022). Therefore, this study postulates the following hypotheses:

H3: Social support positively moderates the relationship between urban digital technology innovation and the well-being of older adults.

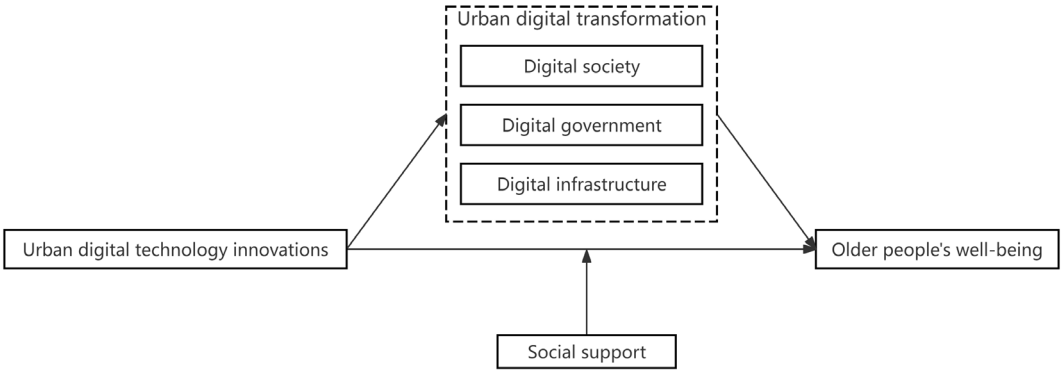

Figure 1. Research framework diagram

Research design

Data collection and sample selection

The data for this study were collected from three sources: Clarivate's IncoPat patent database, China Urban Statistical Yearbook and China Family Tracking Survey (CFPS) data. Specifically, the data related to urban digital technology innovation were obtained from the IncoPat patent database, a significant patent database owned by Clarivate. This database encompasses over 170 million patent documents from 158 countries, organisations, or regions around the world, offering a range of functionalities such as patent search, thematic library, analysis, surveillance and early warning systems. It provides comprehensive, accurate, and up-to-date innovation Intelligence. In

accordance with China's patent regulations, invention patents are generally disclosed within 18 months of application, although early or delayed disclosure is possible. In order to accurately compile the quantity of patent applications pertaining to digital technology in each city, this study selected the year 2020 as a reference period. Following the criteria outlined in Ge et al. (2023), the study utilised the IPC classification numbers for digital technology based on the "Core Industry Classification of Digital Economy and International Patent Classification Reference Relationship Table (2023)" issued by China's State Intellectual Property Office. In this study, we used the advanced search within Incopat patent database to retrieve the patent information related to digital technology filed by each city in China during the year 2020. The collected data included patent title, applicant, application number, filing date, patent type, IPC classification number, emerging industry classification number and other information about these invention patents. In total, the dataset comprised 1,317,694 invention patents. Notably, Shenzhen has the highest number of 128,169 digital technology-related patents filed in 2020, while Beijing closely followed with 113,806 such patents filed (Figure 2).

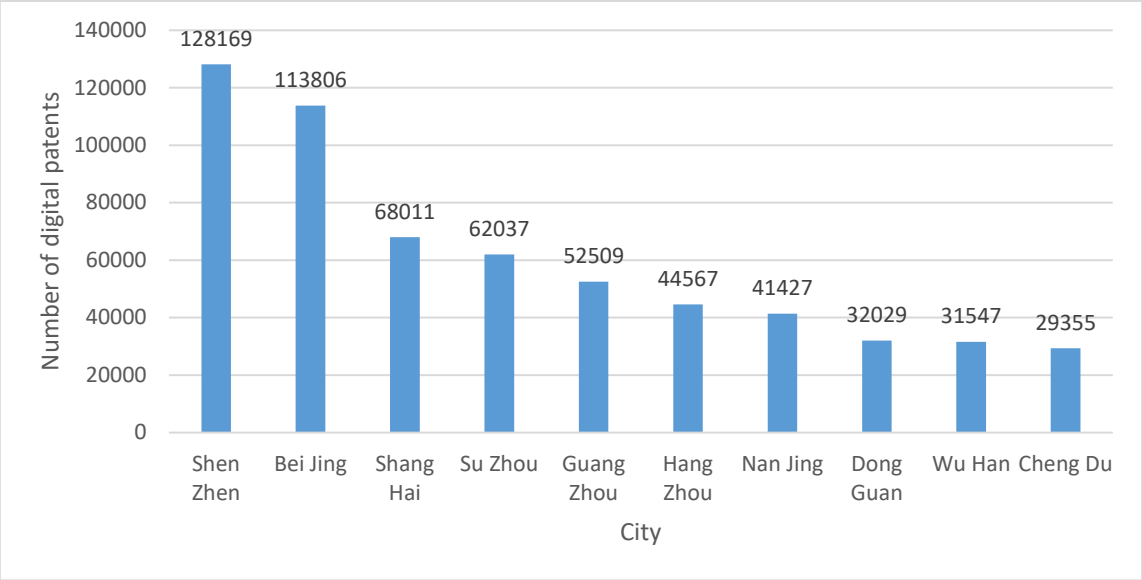

Figure 2. Top 10 cities with the highest number of digital technology-related patent applications in 2020

The data used in this study for urban digital transformation primarily originated from the publicly available statistical yearbook data for each city. To measure urban digital transformation, this study referred to the calculation index system proposed by Xinhua San Technology Co. (Wang et al., 2022), which includes metrics related to digital infrastructure, digital society, and digital government. The values corresponding to these indexes were obtained from the 2020 statistical yearbooks of each city in China. Subsequently, the values of digital infrastructure, digital society, and digital government were calculated for each city in 2020. Regarding data on the well-being of the elderly, including happiness levels, gender distribution of the elderly, and their health status, were obtained from the China Family Tracking Survey (CFPS) 2020 (http://www.isss.pku.edu.cn/cfps/index.htm). The CFPS 2020 survey covers 28,590 individuals in 11,569 households across 25 provinces in China, with a focus on the elderly population aged 60 and above, totaling 6,984 individuals. CFPS aims to capture the changes in various aspects of China's society, such as economics, demographics, education, and health, at individual, household, and community levels. It serves as a comprehensive database for academic research and public policy analysis. In this study, data integration was performed through heterogeneous fusion of information from multiple sources using tools like Python. Then, a total of 5,609 valid samples were

retained. Finally, the study conducted analyses involving main effects, mediating effects, moderating effects, and robustness tests using Stata 19.

Variable Interpretation

Dependent Variable - Urban Digital Technology Innovation

Urban digital technology innovation refers to reforming and innovating in various urban domains utilising modern digital technologies such as information technology, communication technology, the Internet and big data during urban development. These domains encompass but are not limited to urban transportation, health care, social services, living environment, culture, entertainment and social interaction. Urban digital technology innovation is committed to improving the digitalization and intelligence level, optimising urban management and services while improving the quality of life and well-being of urban residents (Castellacci & Tveito, 2018). The number of patents is one of the most critical indicators for measuring innovation activities and technological advancement, which reflects the city's innovation ability and investment level in digital technology. Building upon the studies of Wen (2019) and Hülür & Macdonald (2020), in this study, we use the quantity of patents related to digital technology filed by a specific city in a given year to represent its level of digital technology innovation. When a city has a high level of urban digital technology innovation, it often has a larger quantity of patents related to digital technology, indicating that the city has achieved significant innovation in the field of digital technology. Through this indicator, we can understand the overall level of the city's digital technology innovation. To reduce data volatility, we take the logarithm of the quantity of digital technology-related patents for each city.

Dependent Variable - Older Adults' Well-Being

The well-being of older individuals encompasses their subjective feelings and evaluations regarding their own lives and state of well-being. It is a complex psychological concept, including assessment of life satisfaction, emotional experience, self-realisation, mental health and other aspects. Happiness among older adults serves as an essential indicator of the quality of life during the later stages of life and garners significant societal attention, and it is also one of the focuses of social concern. We measure the well-being of elderly individuals through a comprehensive assessment that includes self-reported happiness levels, derived from the China Family Tracking Survey (CFPS) 2020. This approach follows the methodological framework used in prior research (Wen, 2019), ensuring the validity and reliability of our measurement. Specifically, in this study, we adopted the approach from Wen (2019) and employed the question "How happy do you feel" from the CFPS questionnaire as a measure of happiness. Respondents provided a score ranging from 0 to 10, where 0 indicates the lowest level of happiness and 10 represents the highest level. A higher score corresponds to greater happiness among the elderly.

Mediating variables - the digital transformation of cities

Urban digital transformation refers to the comprehensive upgrading and transformation of a city through the utilisation of information and digital technologies. In this process, cities extensively employ advanced digital technologies, such as big data, artificial intelligence, the Internet of Things and cloud computing to enhance the intelligence of urban management and services, optimise the allocation of urban resources and improve the quality of life for residents. In this study, drawing on Wang et al. (2022) and the China Urban Digital Development Index published by the Xinhua San Technology Co., we assessed the level of urban digital transformation in each city based on three dimensions: digital infrastructure, digital society, and digital government. Among them, digital infrastructure encompasses new infrastructure primarily driven by digital technologies, including network communication, big data, cloud computing, blockchain, artificial intelligence, quantum technology, Internet of Things and industrial Internet, among others. It comprises information infrastructure, platform infrastructure and operation infrastructure. Digital society comprises three main aspects: public services, smart cities and digital villages, and digital life. Within the

aspect of digital life, it further includes new digital life, innovative community, digital family, citizens' digital literacy and information accessibility. Additionally, it includes popular areas of interest and prevalent concerns such as digital inclusion application, city brain, digital countryside, and intelligent court. The construction of digital government constitutes the core and fundamental project of building a network power and digital China. This dimension focuses on assessing the degree of government data openness, digitisation in areas like public security, party building, emergency response, ecology, municipal government, economy and legal governance, as well as the level of implementation of the "one network to do everything"(Wang et al., 2022). Similarly, to reduce the data variability, logarithmic transformations were applied to the data for each city in the dimensions of digital transformation.

Moderating variable - social support

Social support encompasses assistance networks provided by various sources, including family, community, and social organisations. When older adults receive support and assistance from their families, friends, or communities in their use of digital technologies, they may be more likely to adapt and enjoy the benefits of digital technologies, consequently enhancing their well-being. In this study, the measurement of social support is informed by approaches used in studies such as Deichert et al. (2021) and Alsubaie et al. (2019). The CFPS questionnaire was used to assign scores to respondents based their answers to questions such as “Whom do you turn to first when you are sick and in need of care?” and “How frequently do you meet with your different children each month?”. For responses indicating "son", "daughter," "other relatives," and "social care worker", a higher total score indicates that the older person receives more substantial social support.

Control variables

Drawing from existing studies, this study controlled for variables that could potentially influence the well-being of the elderly, including gender, current marital status, insurance coverage and health status. Gender: Females were coded as 0, while males were coded as 1. Current marital status: Unmarried individuals were coded as 0, divorced or widowed individuals were coded as 1, and those currently married (with a spouse) were coded as 2. Insurance coverage: Older adults without any form of insurance were coded as 0, while those with insurance coverage were coded as 1. Health status: The questionnaire included a question labeled "QP201 Health Status", which asked respondents to rate their own health status on a scale from 1 to 7, with higher scores indicating better health.

Variable type	Variable name	variable symbol
implicit variable	Older people's well-being	OPWB
independent variable	Urban digital technology innovation	UDTI
intermediary variable	Digital Infrastructure	DI
	Digital Society	DS
	Digital Government	DG
moderator variable	Social Support	SS
control variable	Gender	Gender
	Current Marital Status	CMS
	Insured or not	IN
	Health Status	HS

Table 1. Symbols of variables

Modeling

In this study, to reveal the relationship between urban digital technology innovation, urban digital transformation, social support, and the happiness of the elderly, the OLS mixed-effects model was employed. Specifically, digital technology innovation was used as the independent variable, the happiness of the elderly as the dependent variable, the three dimensions of urban digital transformation (digital infrastructure, digital society, and digital government) were employed as mediating variables. Social support was considered as the moderating variable. The following empirical model was constructed to test the hypotheses.

First, considering the impact of urban digital technology innovation on the well-being of the elderly individuals, i.e., hypothesis H1. The specific model is as follows:

$$OPWB_i=\beta_0+\beta_1 UDTI_i+\gamma Controls+\varepsilon_i \quad (1)$$

Where OPWB represents the elderly well-being of older adults; UDTI represents the levels of urban digital technological innovation; Controls is the control variables, including gender, current marital status, insurance coverage, and health status; and i represents the sampled individuals, and ε_i represents the residual term.

Second, when examining the mediating effects of the three dimensions of urban digital transformation, i.e., hypotheses H2a, H2b, and H2c, a three-step approach was used. This study tested the mediating effects of digital infrastructure, digital society, and digital government within the framework of digital transformation. The specific model are as follows:

$$OPWB_i=\beta_2+\beta_3 UDTI_i+\gamma Controls+\varepsilon_i \quad (2)$$

$$DI_i=\beta_4+\beta_5 UDTI_i+\gamma Controls+\varepsilon_i \quad (3)$$

$$DS_i=\beta_6+\beta_7 UDTI_i+\gamma Controls+\varepsilon_i \quad (4)$$

$$DG_i=\beta_8+\beta_9 UDTI_i+\gamma Controls+\varepsilon_i \quad (5)$$

$$OPWB_i=\beta_{10}+\beta_{11} UDTI_i+\beta_{12}\, DI_i+\gamma Controls+\varepsilon_i \quad (6)$$

$$OPWB_i=\beta_{13}+\beta_{14} UDTI_i+\beta_{15}\, DS_i+\gamma Controls+\varepsilon_i \quad (7)$$

$$OPWB_i=\beta_{16}+\beta_{17} UDTI_i+\beta_{18}\, DG_i+\gamma Controls+\varepsilon_i \quad (8)$$

DI represents the mediating variable of Digital Infrastructure, DS represents the mediating variable of Digital Society, DG represents the mediating variable of Digital Government, and the other variables remain as mentioned above.

Third, to explore the moderating effect of social support in the relationship between urban digital technology innovation and the well-being of the elderly, i.e., Hypothesis H3. The specific model is as follows:

$$OPWB_i=\beta_{19}+\beta_{20} UDTI_i+\beta_{21}\, UDTI*SS_i+\gamma Controls+\varepsilon_i \quad (9)$$

Where SS represents the moderator variable of social support, UDTI*SS represents the interaction term between urban digital technology innovation and social support, while the other variables remain the same as mentioned above.

Results

Descriptive statistical analysis

Descriptive statistics of the main variables were conducted in this study (Table 2). The standard deviations of the main variables in the sample data are all within the normal range, suggesting that the variables are not heavily affected by extreme values. The minimum happiness score reported by the elderly across the 111 surveyed cities was 0, while the maximum score reached 10, indicating a significant variation in the happiness levels of the elderly across different cities. The minimum value of digital technological innovation in the 111 cities was 4.771, with a maximum value was 11.761. Regarding the social support variable, the minimum value recorded was 0, while the maximum value reached 8. Therefore, based on the distributional characteristics of these variables, they were deemed suitable for the Pearson correlation analysis and subsequent regression analysis.

Variable	N	Mean	p50	SD	Min	Max.
OPWB	5609	7.601	8	2.267	0	10
UDTI	5609	8.537	8.589	1.926	4.771	11.761
DI	5609	4.247	4.315	0.259	3.653	4.554
DS	5609	4.127	4.134	0.29	3.431	4.532
DG	5609	4.067	4.138	0.319	3.421	4.51
SS	5609	1.949	2	1.579	0	8
Gender	5609	1.496	1	0.5	1	2
CMS	5609	1.661	2	0.643	0	2
IN	5609	0.704	1	0.456	0	1
HS	5609	1.666	1	1.551	1	7

Table 2. Descriptive statistics of relevant variables

In terms of the degree of urban digital transformation, the top 20 cities with the highest level of digital transformation in 2020 are listed in Figure 3. These cities are Shanghai, Shenzhen, Beijing, Chengdu, Hangzhou, Guangzhou, Wuxi, Ningbo, Chongqing, Wuhan, and Nanjing. Specially, Shanghai has a digital infrastructure index of 92.3, a digital society index of 91.7, and a digital government index of 87.8; Shenzhen has a digital infrastructure index of 95, a digital society index of 92.6, and a digital government index of 89.5; Beijing has a digital infrastructure index of 91.1, a digital society index of 87, and a digital government index of 90.3; Chengdu has a digital infrastructure index is 92, digital society index is 90.9, and digital government index is 89.2; Hangzhou's digital infrastructure index is 89.9, digital society index is 92.9, and digital government index is 90.9.

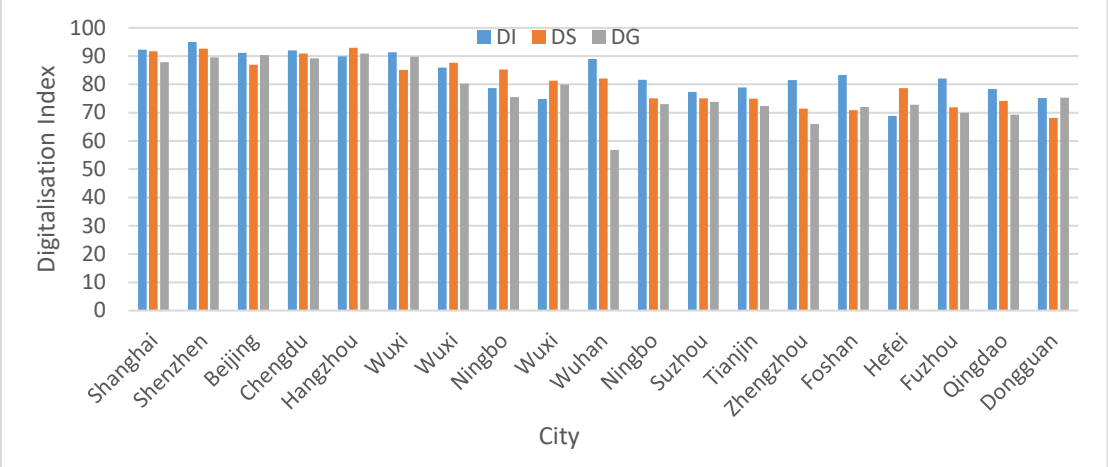

Figure 3. Top 20 digitised cities

Regarding the correlation between each variable and the dependent variable, innovation performance (Table 3), there exists a significant positive correlation between the variables of urban digital technology innovation, digital infrastructure, digital society, digital government, social

support, and the well-being of the elderly. Moreover, this study conducted a test for the variance inflation factor (VIF). The VIF values ranged from a minimum value of 1.01 to a maximum of 6.94, with a mean value was 2.12. The VIF values of the variables were much less than 10, indicating the absence of multicollinearity issues and confirming the suitability of the dataset for regression analysis.

	OPWB	UDTI	DI	DS	DG	SS	Gender	CMS	IN	HS
OPWB	1									
UDTI	0.134***	1								
DI	0.155***	0.882***	1							
DS	0.136***	0.947***	0.905***	1						
DG	0.150***	0.930***	0.911***	0.941***	1					
SS	0.108***	-0.186***	-0.106***	-0.159***	-0.156***	1				
Gender	-0.019	-0.001	-0.01	-0.004	-0.002	0.019	1			
CMS	0.161***	-0.060***	0.017	-0.030**	-0.011	0.326***	-0.130***	1		
IN	0.134***	-0.067***	0.005	-0.029**	-0.013	0.199***	-0.042***	0.392***	1	
HS	0.015	0.007	0.083***	0.025*	0.032**	0.086***	-0.02	0.095***	0.091***	1

Table 3. Pearson correlation analysis

* p < 0.1,** p < 0.05,*** p < 0.01

Main effects analysis

In order to investigate the direct impact of urban digital technological innovations on the well-being of the elderly individuals, this study employed an OLS model and conducted a stepwise addition of variables for examination. In Table 4 , column (1) shows the regression results of the relationship between urban digital technology innovation and the well-being of the elderly without the inclusion of control variables, with the regression coefficient of 0.158***, which is significant at the p<0.01 level. It can be observed that when a city has stronger digital technology innovation capabilities, older adults tend to experience higher levels of well-being. Column (2) includes gender as a control variable; column (3) adds current marital status as an additional control variable; column (4) includes the presence of insurance as a control variable; column (5) further adds health status as a control variable. Notably, as control variables are progressively added, the regression coefficient consistently remains significant at the p<0.01 level and positive. This indicates that there is a positive correlation between a city's digital technology innovation capacity and the well-being of the elderly, thereby confirming hypothesis H1.

	(1) OPWB	(2) OPWB	(3) OPWB	(4) OPWB	(5) OPWB
UDTI	0.158***	0.158***	0.170***	0.174***	0.175***
	(10.13)	(10.13)	(11.04)	(11.38)	(11.38)
Gender		-0.0856	0.0152	0.0116	0.0113
		(-1.43)	(0.25)	(0.20)	(0.19)
CMS			0.601***	0.475***	0.477***
			(12.93)	(9.45)	(9.47)
IN				0.455***	0.457***
				(6.48)	(6.50)
HS					-0.0104
					(-0.54)
_cons	6.254***	6.383***	5.131***	4.985***	4.997***
	(45.89)	(39.10)	(27.33)	(26.45)	(26.33)
N	5609	5609	5609	5609	5609
R^2	0.018	0.018	0.047	0.054	0.054
adj. R^2	0.018	0.018	0.046	0.053	0.053

Table 4. Main effects test results

* p < 0.1,** p < 0.05,*** p < 0.01

Analysis of intermediation effects

Table 5 presents the test results of the mediating effects of urban digital transformation. This study utilises the hierarchical regression method to examine the significance of the mediating effects in the three dimensions of digital infrastructure, digital society, and digital government within urban

digital transformation. The method consists of three main steps: in the first step, the relationship between the independent variable urban digital technological innovation and the dependent variable, the well-being of elderly individuals, is tested. This corresponds to column (1) in Table 5. In the second step, the relationships between the independent variable of urban digital technology innovation and the mediating variables of digital infrastructure, digital society and digital government, were examined. These relationships are represented in columns (2), (3) and (4) of Table 5. We find a significant positive relationship between urban digital technology innovation and digital infrastructure, society, and government. In the third step, the relationship between independent variables, mediating variables, and dependent variables are tested. This step is reflected in columns (5), (6) and (7) of Table 5. The results consistently show significant positive relationships. This suggests that digital infrastructure, digital society and digital government mediate between urban digital technology innovation and the well-being of the elderly individuals. Therefore, this study's hypotheses H2a, H2b, and H2c are verified.

	(1) OPWB	(2) DI	(3) DS	(4) DG	(5) OPWB	(6) OPWB	(7) OPWB
UDTI	0.175***	0.119***	0.143***	0.155***	0.0663**	0.146***	0.0494**
	(11.38)	(144.07)	(223.29)	(192.29)	(2.00)	(3.03)	(1.17)
Gender	0.0113	-0.000122	-0.000152	0.00288	0.0114	0.0113	0.00899
	(0.19)	(-0.04)	(-0.06)	(0.92)	(0.19)	(0.19)	(0.15)
CMS	0.477***	0.0191***	0.00648***	0.0142***	0.459***	0.475***	0.465***
	(9.47)	(7.05)	(3.08)	(5.38)	(9.09)	(9.44)	(9.22)
IN	0.457***	0.0228***	0.0176***	0.0262***	0.437***	0.454***	0.436***
	(6.50)	(6.02)	(5.99)	(7.10)	(6.19)	(6.43)	(6.18)
HS	-0.0104	0.0114***	0.00271***	0.00406***	-0.0207	-0.0109	-0.0137
	(-0.54)	(11.04)	(3.39)	(4.06)	(-1.08)	(-0.57)	(-0.72)
DI					0.909***		
					(3.67)		
DS						0.198**	
						(0.62)	
DG							0.810***
							(3.18)
_cons	4.997***	3.163***	2.876***	2.695***	2.121***	4.426***	2.814***
	(26.33)	(309.33)	(362.32)	(270.98)	(2.63)	(4.72)	(3.95)
N	5609	5609	5609	5609	5609	5609	5609
R^2	0.054	0.789	0.899	0.869	0.056	0.054	0.056
adj. R^2	0.053	0.789	0.899	0.868	0.055	0.053	0.055

Table 5. Results of the mediation effect test

* p < 0.1,** p < 0.05,*** p < 0.01

Analysis of moderating effects

Table 6 examines whether social support plays a moderating role between urban digital technology innovation and the well-being of the elderly individuals. In column (1), after controlling for all variables, it is observed that urban digital technology innovation has a significant positive impact on the well-being of older adults, with a regression coefficient of 0.175***. In column (2), the interaction term between urban digital technology innovation and social support on the well-being of the elderly individuals is tested. It is found to have a significant positive effect, with a regression coefficient of 0.171***. Therefore, social support positively moderates the relationship between

urban digital technology innovation and the well-being of the elderly individuals, confirming hypothesis H3.

	(1)	(2)
	OPWB	OPWB
UDTI	0.175***	0.171***
	(11.38)	(11.08)
Gender	0.0113	-0.000782
	(0.19)	(-0.01)
CMS	0.477***	0.433***
	(9.47)	(8.25)
IN	0.457***	0.445***
	(6.50)	(6.32)
HS	-0.0104	-0.0141
	(-0.54)	(-0.74)
UDTI*SS		0.00694***
		(2.96)
_cons	4.997***	5.026***
	(26.33)	(26.47)
N	5609	5609
R^2	0.054	0.055
adj. R^2	0.053	0.054

Table 6. Moderating effect test results of social support

* p < 0.1,** p < 0.05,*** p < 0.01

Robustness Tests

In order to further assess the robustness of the findings, this study uses two robustness testing methods: dataset reduction and lagged dependent variable regression. First, a 5% dataset reduction treatment is applied to the sample dataset. The results indicate that the regression coefficient between the independent variable, urban digital technology innovation, and the well-being of the elderly remains significantly positive when control variables are sequentially added (Table 7).

	(1) OPWB	(2) OPWB	(3) OPWB	(4) OPWB	(5) OPWB
UDTI	0.142***	0.142***	0.153***	0.158***	0.158***
	(9.69)	(9.69)	(10.57)	(10.90)	(10.91)
Gender		-0.0678	0.0242	0.0209	0.0205
		(-1.20)	(0.43)	(0.37)	(0.37)
CMS			0.549***	0.431***	0.433***
			(12.51)	(9.09)	(9.11)
IN				0.426***	0.429***
				(6.43)	(6.46)
HS					-0.0122
					(-0.68)
_cons	6.438***	6.540***	5.397***	5.260***	5.275***
	(50.13)	(42.51)	(30.48)	(29.59)	(29.47)
N	5609	5609	5609	5609	5609
R^2	0.016	0.017	0.043	0.050	0.051
adj. R^2	0.016	0.016	0.043	0.050	0.050

Table 7. Regression analysis after 5% deflation

* p < 0.1,** p < 0.05,*** p < 0.01

Subsequently, this study uses the lagged independent variable regression method for analysis, which contributes to enhancing the robustness of the results to a certain extent. Since there is a certain time lag in the impact of urban digital technology innovation on the well-being of the elderly, it is important to account for this delay in the analysis. . However, the data for the elderly in this study are from 2020. Therefore, this study considers using the data to calculate the urban digital technology innovation for 2018. The impact of urban digital technology innovation on the happiness of the elderly remains significant, with a lag of 2 periods (Table 8). Moreover, in comparison to the regression coefficient before implementing the lag treatment, the regression coefficient after applying the lag treatment becomes significantly more prominent.

	(1) OPWB	(2) OPWB	(3) OPWB	(4) OPWB	(5) OPWB
UDTI	0.508***	0.508***	0.821***	0.887***	0.888***
	(4.03)	(4.02)	(6.49)	(7.02)	(7.02)
Gender		-0.0855	0.0202	0.0173	0.0171
		(-1.41)	(0.34)	(0.29)	(0.28)
CMS			0.628***	0.505***	0.507***
			(13.20)	(9.89)	(9.89)
IN				0.457***	0.459***
				(6.45)	(6.47)
HS					-0.00853
					(-0.44)
_cons	7.525***	7.652***	6.404***	6.280***	6.291***
	(210.70)	(78.66)	(47.57)	(46.35)	(45.70)
N	5609	5609	5609	5609	5609
R^2	0.003	0.003	0.033	0.040	0.040
adj. R^2	0.003	0.003	0.033	0.040	0.040

Table 8. Regression analysis of digital technology innovation II

* p < 0.1,** p < 0.05,*** p < 0.01

Discussion and conclusions

Discussion

The mediating role of urban digital transformation

Our study confirms the critical role of urban digital transformation in enhancing the well-being of the elderly, aligning with our research hypothesis that digital transformation positively impacts elderly well-being through various mediating variables. Urban digital transformation integrates digital technologies such as advanced information technology, communication technology, and the Internet into urban life to improve governance, optimise resource allocation and enhance residents' quality of life.

Digital Infrastructure: Our results show that digital infrastructure significantly mediates the relationship between urban digital technological innovation and elderly well-being. Technologies like the Internet of Things (IoT) and smart home devices offer older people a more convenient and comfortable living environment, directly impacting their well-being (Barnard et al., 2013). Intelligent home devices, including innovative security systems and smart appliances, enable older individuals to manage their homes more effectively, increasing convenience and safety (Ciasullo et al., 2020; Jiao & Sun, 202). Additionally, access to entertainment and learning resources through digital infrastructure, such as online education platforms, enriches their quality of life (Zhou, 2013).

Therefore, our findings support the hypothesis that digital infrastructure acts as a mediating variable, enhancing the positive effects of digital innovation on elderly well-being.

Digital Society: The digital society facilitates social interaction and participation for older people, supporting our hypothesis that social integration through digital means improves their well-being. Digital platforms enable older individuals to communicate and interact with family, friends and community members, reducing social isolation (Hülür & Macdonald, 2020). The popularity of online social activities provides more opportunities for social engagement, which is associated with higher life satisfaction and well-being (Cotten, 2022; Lou, 2010). This aligns with our findings that digital socialisation serves as a mediating variable, reinforcing the connection between digital technology innovations and elderly well-being.

Digital Government: Our study demonstrates that digital government services enhance elderly well-being by providing more convenient and efficient public and governmental services. Digital government allows older people to complete transactions from home, avoiding long queues and energy-consuming processes (Mouna & Jarboui, 2022). Digital healthcare services offer expedited medical consultations and telemedicine options, improving health management for the elderly. Moreover, digital decision-making in urban planning and resource allocation, such as intelligent transportation systems, improves travel safety and ease for the elderly (Ibrahim, 2003). These findings confirm our hypothesis that digital government acts as a mediating variable, linking digital innovation with improved well-being for the elderly.

In summary, urban digital transformation, through its components of digital infrastructure, digital society, and digital government, significantly mediates the relationship between urban digital technological innovation and the well-being of the elderly. These mediating variables underscore the transformative potential of digital technologies in enhancing elderly well-being, supporting our research hypothesis and the study's results.

The moderating role of social support

Our study demonstrates that social support significantly moderates the relationship between urban digital technology innovation and the well-being of older individuals, confirming our research hypothesis. Social support is a crucial resource for older individuals navigating the digital era, influencing their acceptance and utilisation of digital technologies, which in turn affects their well-being. The findings indicate that social support assists elderly individuals in overcoming challenges associated with learning and adapting to new technologies. Social support provides the necessary assistance and guidance, boosting older adults' confidence and interest in digital technologies (Deichert et al., 2021; Gan et al., 2020). This aligns with the hypothesis that social support moderates the impact of digital innovation on well-being by enhancing technology adoption. Studies have shown that social support reduces fears and anxieties about new technologies, making older adults more willing to use them (Alsubaie et al., 2019; Perdana & Mokhtar, 2022). Consequently, with adequate social support, older individuals can better utilise digital technologies to access health information, engage in social interactions and obtain various services, ultimately improving their well-being.

Social support also enhances older adults' sense of social integration and self-actualization, which are critical for their well-being. Our results support the hypothesis that social support moderates the relationship between digital innovation and well-being by fostering social inclusion. Social support helps older individuals integrate into the digital landscape, expanding their social networks and mitigating social isolation (Papa et al., 2016). Furthermore, it encourages participation in community activities and volunteerism, fostering a sense of purpose and fulfillment (Liu et al., 2022). These positive social interactions and a sense of self-actualization significantly contribute to the well-being of older adults.

In conclusion, our study underscores the vital role of social support in moderating the effects of urban digital technology innovation on the well-being of older individuals. Social support not only facilitates the adoption and effective use of digital technologies but also enhances social integration and self-actualization, thereby amplifying the positive impact of digital innovation on the well-being of the elderly. This finding is consistent with our research hypothesis and supports the study's overall results.

Limitations

While this study significantly contributes to our understanding of the impact of urban digital technology innovations on the well-being of older adults and the related mechanisms, it is not without limitations. Firstly, the study sample consisted exclusively of older adults from specific cities in China, which may limit the generalisability of the findings. Older adults in different cities and countries may experience varying degrees of urban digital transformation and levels of social support. Therefore, the applicability of the study's results to cities in other countries should be further examined. To enhance the credibility and broad applicability of the findings, future studies could expand the sample to include urban older adults from diverse urban settings in different countries or regions, ensuring the results' representativeness. Secondly, this study employed a cross-sectional design and lacked a long-term follow-up to capture the sustained impact of urban digital technology innovation on the well-being of older adults. Over time, urban digital transformation and social support levels may change, and a long-term longitudinal survey could provide deeper insights into how these changes affect the well-being of older adults. Therefore, future research could adopt a longitudinal research design to explore the enduring impact of urban digital technological innovations on the well-being of the elderly and the evolving patterns of change through data collection at multiple consecutive points. Lastly, this study exclusively examined the impact of urban digital transformation and social support on older adults' sense of well-being.

In contrast, well-being is influenced by a complex interplay of multiple factors. For example, individual characteristics, socioeconomic status, health status, and family relationships may also exert significant effects on the well-being of older adults. Future research could delve deeper into the role of these factors in shaping well-being and analyse how they interact with digital technological innovation and social support within urban contexts. This study has primarily discussed these aspects from a quantitative perspective; however, future endeavors will aim to integrate both quantitative and qualitative approaches to offer a more comprehensive understanding. Continuous efforts and improvements can contribute to the creation of a more favorable and joyful digital future for elderly individuals.

Conclusion

This study investigated the impact of urban digital technology innovation on the well-being of elderly individuals in Chinese cities. The findings reveal that urban digital technology innovation significantly enhances the well-being of older adults. Specifically, digital technology provides elderly individuals with greater opportunities for social interaction, access to information and improved health management. Furthermore, the study identifies urban digital transformation, including digital society, digital government and digital infrastructure, as key mediating factors that amplify the positive effects of digital technology on elderly well-being. Additionally, social support plays a crucial moderating role, further strengthening the beneficial impact of digital technology innovation on the well-being of the elderly. Through robust empirical analysis, this research underscores the importance of integrating social support mechanisms within the framework of urban digital transformation. The results suggest that policymakers and social practitioners should focus on enhancing digital infrastructure and fostering supportive social networks to maximise the positive outcomes of digital technology for the elderly population. Overall, this study contributes valuable insights into the interplay between digital innovation and

social support, offering practical guidance for improving the quality of life and social integration of elderly individuals in the digital age.

Acknowledgements

Funding: This research was funded by the National Social Science Fund of China Youth Project – "Research on the Transformation and Upgrading of Social Work Intervention Models for Elderly Loneliness from the Perspective of Active Aging" (Project Number: 22CSH057), and the Doctoral Research Start-up Fund of Guangdong Medical University – "Translation Fees for the Study on the Application and Improvement of Innovative Techniques in Elderly Social Work Services" (Project Number: GDMUB2023021).

About the authors

Yajing Wu is a graduate student at Guangdong University of Foreign Studies, Teaching Assistant at Guangdong Medical University. Her main research areas are health informatics, digital technology innovation, and health information behavior. wuyajing2023@gmail.com

Xianglei Zhu is a lecturer at the School of Humanities and Management, Guangdong Medical University. Part-time supervisor for social work postgraduate students at Guangdong University of Foreign Studies. Secretary General of the Dongguan Health and Elderly Care Association. His primary research interests include health informatics, digital technology innovation, health information behavior, social work, and quality management and innovation in elderly care services. zhuxl2020@gdmu.edu.cn

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