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TRANSFORMING CHINA'S DEMOGRAPHIC CHALLENGES: TECHNOLOGY, THE SILVER ECONOMY, AND SUSTAINABLE ECONOMIC GROWTH

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Abstract

This rigorous study investigates the profound impact of rapid population aging on China's economic growth, with a particular emphasis on the mitigating roles of technological innovation and the emerging silver economy. Utilizing a robust panel dataset spanning 31 Chinese provinces from 2005 to 2021, the research employs a fixed-effects regression model with three nested specifications to systematically evaluate these complex dynamics. The empirical results demonstrate that while an aging demographic significantly constrains per capita GDP by reducing the efficient labor supply and elevating dependency ratios, these negative macroeconomic effects are not absolute. Crucially, the targeted expansion of digital infrastructure and technological advancement substantially moderates this economic deceleration. Furthermore, the proactive development of the silver economy—specifically measured by enhanced elder-care capacity—serves as a positive catalyst for long-term regional economic resilience. Notably, aging-related fiscal burdens, such as pension expenditures, did not have severe adverse effects when adequately offset by targeted investments in the elder sector and robust local urbanization. Ultimately, these findings provide policymakers with actionable insights to transform demographic constraints into opportunities for sustainable economic growth through strategic digitalization and targeted expansions in the senior market.

Keywords: Population Aging, Silver Economy, Technological Innovation, Digital Economy, Economic Growth

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Introduction

Aging is described as “a dynamic process in which the proportion of young people in a population gradually decreases, while the share of elderly individuals increases, driven by fewer births and extended life spans”. Broad consensus holds that “a society is considered aging when individuals aged 60 and above make up at least 10% of the population, or those aged 65 and above exceed 7%”. Over recent decades, China’s declining birth rate—largely influenced by the family planning policy and sustained economic development—has dramatically altered its demographic composition. Concurrently, rising living standards and advances in healthcare have increased life expectancy, accelerating China’s transition into an aging society. According to the Seventh National Census, the population aged 60 and above reached 264.02 million (18.7% of the total), while those aged 65 and above totaled 190.64 million (13.5%). These figures illustrate a significant rise in the aging population compared with the Sixth National Census in 2010, and this trend is expected to intensify in the coming years (Liu et al., 2023).

The influence of population aging on China’s social and economic development has been widely acknowledged, primarily through two channels. First, the reduced supply of efficient labor challenges enterprises’ productivity and threatens the sustainability of long-term economic growth (Bank of China, 2022). Second, an increasingly large elderly population demands higher pension, healthcare, and social welfare expenditures, placing considerable strain on government finances (Chen, 2023). Without effective reforms, the pension funding gap—currently near 2% of GDP—could exceed 10% of GDP in the coming decades (Xiao, 2023). Against this backdrop, classic research has largely focused on how aging constrains labor supply and raises public welfare costs. However, there remains a notable gap in the literature regarding the emerging structural and technological transformations that could either exacerbate or counterbalance the negative effects of aging (Zhang et al., 2023). Specifically, with the accelerated digitalization of the Chinese economy and the rise of new consumption patterns (e.g., online retail, fintech services), the interplay between an aging demographic and innovation-driven growth remains underexplored. Moreover, despite numerous macro-level studies, regional disparities (urban-rural gaps and interprovincial migration trends) and firm-level adjustments (e.g., investment in automation, shifts in corporate human resource strategies) have not been comprehensively investigated. Furthermore, the surge in a “silver economy”—referring to the markets and industries serving the needs of older citizens—could create new growth engines (Peng et al., 2023). However, research on how this sector can be systematically integrated into China’s industrial policy remains in its infancy.

To address these critical gaps, this study outlines three primary objectives. First, it aims to examine the mediating role of technological innovation and digitalization. While many studies emphasize declining labor force participation, fewer analyses dissect how technology and digital platforms can offset or transform the negative effects of an aging workforce; thus, this research will explore whether automation, artificial intelligence, and fintech solutions can sustain productivity and reconfigure labor market dynamics. Second, the study seeks to explore the emergence of the silver economy and new consumption patterns. In addition to the traditional burden narrative, the study focuses on the rise of specialized industries catering to older populations (e.g., elderly healthcare, senior tourism, assistive technology) to examine how the silver economy could become a new growth engine, and what regulatory support is necessary to foster sustainable development in this sector. Finally, this research intends to analyze policy mechanisms and their effectiveness. Beyond discussing pension and social welfare reforms, the study evaluates how innovative measures—such as encouraging older adults’ re-entry into the labor market, promoting flexible retirement schemes, and integrating AI-driven healthcare—could alleviate fiscal pressure, maintain growth momentum, and actively shape the industrial structure.

Literature Review

In recent years, multiple studies have indicated that China rapidly entered an aging society after the turn of the 21st century. According to the Seventh National Population Census, as of 2020, the population aged 65 and above in China reached 190.6 million, accounting for 13.5% of the total population—an increase of 4.63 percentage points from the previous census, signifying a marked acceleration of the aging process (Bank of China, 2022). Two key factors are typically cited to explain this phenomenon: persistently low fertility rates and advances in healthcare (Organisation for Economic Co-operation and Development, 2020). The demographic shift is mainly driven by a consistently low fertility rate that results in a decline in the young population, alongside improvements in medical technology and health security that have significantly prolonged the lifespan of the elderly (Chen, 2023). Additionally, scholars highlight that China's "culture of longevity," prevalent throughout society, also shapes individual attitudes and social norms, thereby adding distinctive characteristics to the country's demographic evolution (Xiao, 2023).

Recent empirical studies have rigorously examined the multifaceted relationship between population aging and China's economic growth using diverse datasets and econometric approaches. Liu et al. (2023) employed static and dynamic panel data models and found that aging inhibits economic growth through the channel of industrial structure upgrading, revealing a mediating effect of industrial transformation. In contrast, Chen et al. (2022) used an entropy-based aging index to examine insurance expenditures, demonstrating that in more developed regions, aging can have a positive impact through increased spending on pensions and healthcare. Exploring possible non-linearities, Liang et al. (2023) applied a panel threshold regression (PTR), showing that the economic impact of aging differs by region and is shaped by thresholds such as trade volume and unemployment rates. Furthermore, Zhang et al. (2023) employed a panel vector autoregression (PVAR) model, revealing that aging suppresses household consumption while stimulating national savings, thereby influencing long-term sustainable development. Collectively, these studies underscore that while aging generally poses headwinds to economic growth, the magnitude and mechanisms vary significantly across regions (Bloom et al., 2008).

To address these macroeconomic headwinds, other scholars have incorporated spatial, technological, and policy perspectives to identify potential mitigating factors. Using a system GMM estimator, Zhao et al. (2018) found that while both aging and financial deepening individually promote growth, their interaction dampens growth. Taking a descriptive comparative approach, Xiao (2023) showed that China's aging trend will continue to strain labor markets and challenge economic policymaking. From a policy standpoint, the Bank of China (2022) emphasized that structural reforms—such as pension adjustments, birth-rate policies, and demographic management—are essential to mitigate the economic risks associated with an aging population. Crucially, Zhang et al. (2024) analyzed data using a bidirectional fixed spatial Durbin model and mediation analysis, finding that the digital economy can effectively offset the negative effects of aging on high-quality growth.

In conclusion, population aging in China directly affects economic growth by constraining the labor supply and indirectly influences it through consumption, savings, and fiscal expenditures. However, China possesses unique institutional advantages and the capacity for policy innovation. If the country can effectively expand its social security system, implement prudent financial reforms, and adopt supportive population and elderly care policies, it may largely mitigate the challenges posed by aging and achieve a more sustainable pattern of economic growth. Building upon this conceptual foundation and the extended research objectives, this study posits two core hypotheses. First, it is hypothesized that aging exerts significant negative effects on economic growth. Second, the study proposes that technological innovation and the digital economy significantly reduce the negative impact of aging on economic growth.

Research Methodology

Population and Sample

This study investigates the impact of population aging on economic growth across Chinese provinces from 2005-2021 using a panel data approach. The primary econometric method used is the fixed-effects model (FEM), which controls for unobserved, time-invariant heterogeneity across provinces.

This panel dataset covers data from 31 provinces in China over 17 years (2005-2021). The dependent variable is GDP per capita, which measures economic growth. The key independent variables are the aging rate, measured by the proportion of the population aged 65 and above; technological development; and silver economy indicators, such as elderly consumption. Control variables include urbanization rate and government investment.

Specification 1 (Baseline)

$$GDP_{it} = \alpha_i + \beta_1 Ageing_{it} + \gamma X_{it} + \varepsilon_{it} \quad (1)$$

Specification 2 (Technological Mediation)

$$GDP_{it} = \alpha_i + \beta_1 Ageing_{it} + \beta_2 Tech_{it} + \beta_3 (Ageing_{it} \times Tech_{it}) + \gamma X_{it} + \varepsilon_{it} \quad (2)$$

Specification 3 (Comprehensive Channel Model)

$$GDP_{it} = \alpha_i + \beta_1 Ageing_{it} + \beta_2 Tech_{it} + \beta_3 (Ageing_{it} \times Tech_{it}) + \beta_4 Silver_{it} + \gamma X_{it} + \varepsilon_{it} \quad (3)$$

In this study, the dependent variable $GDP_{i,t}$ represents the real per capita GDP of a province i in year t , capturing the level of economic development. The term α_i denotes the province-specific fixed effect, which controls for unobserved and time-invariant heterogeneity across provinces. The key explanatory variable, $Ageing_{i,t}$ measures the aging rate, defined as the share of the population aged 65 and above in province i and year t . To examine potential moderating factors, $Tech_{i,t}$ represents technological development, proxied by the broadband internet penetration rate, measured as the number of broadband internet users per 100 persons. $Silver_{i,t}$ captures the development of the silver economy, measured by the number of elderly care beds per 1,000 people, which reflects the capacity and infrastructure of the province's elder care service system—an essential component of the silver economy. Finally, $X_{i,t}$ is a vector of control variables that includes other factors that may affect economic output, such as the urbanization rate, government investment, and pension security.

Data Collection

This study relies exclusively on secondary data from official, highly credible national databases. The provincial-level panel data spanning 2005 to 2021 were systematically collected from the China Statistical Yearbook, the China Civil Affairs Statistical Yearbook, and the Statistical Bulletin of the Communications Industry published by the Ministry of Industry and Information Technology (MIIT). Utilizing these authoritative sources ensures the reliability, consistency, and validity of the demographic, technological, and macroeconomic indicators employed in the empirical analysis.

Data Analysis

The fixed effects model (FEM) is mainly used to control for time-invariant individual characteristics across research units, thereby more accurately analyzing the impact of time-varying factors on the dependent variables. In FEM, each individual (such as different provinces, countries, or companies) has unique characteristics that may affect the regression results but do not change over time. FEM effectively avoids omitted variable bias by treating these fixed characteristics as constants and removing their effects from the model, thereby focusing on how changes in independent variables affect dependent variables. For example, when studying the impact of the aging rate of various provinces in China on economic growth, FEM can control fixed factors such as the economic foundation and policy environment of different provinces, making the analysis results more accurate and reliable.

Table 1 Various indicators of China's population age structure

Year	0-14 (%)	15-64 (%)	65 and Above (%)	Dependency Ratio (Old to Young)	Dependency Ratio (Old to Working-Age)
1953	36.3	59.3	4.4	12.16	7.4
1964	40.7	55.8	3.6	8.75	6.4
1982	33.6	61.5	4.9	14.62	8.0
1990	27.7	66.7	5.6	20.11	8.3
1999	25.4	67.7	6.9	27.16	10.2
2000	22.9	70.1	7.0	30.41	9.9
2010	16.6	74.5	8.9	53.43	11.9
2015	16.5	73.0	10.5	63.63	14.3
2020	17.9	68.6	13.5	75.42	19.7

From 1953-1964, China's population age structure exhibited characteristics of a youthful society. During this period, the proportion of children aged 0-14 increased, while the share of the elderly population aged 65 and above declined. This indicates a phase of population rejuvenation in China, with slow growth in the elderly population and stagnation in the elderly population's share of the total population.

Between 1982 and 1999, China's population age structure transitioned to an adult society. This shift was primarily influenced by the family planning policy introduced in the late 1970s, which led to a significant, sustained decline in the share of children aged 0-14. In contrast, the share of the elderly population steadily increased. This change marked a fundamental shift in the population structure, characterized by lower birth rates and lower mortality rates, which are typical of an adult society.

Since 2000, China's population age structure has gradually shifted toward an aging society. During this period, the proportion of children aged 0-14 continued to decline slightly, while the share of the elderly population aged 65 and above increased consistently, surpassing the 7% threshold. Although the relaxation of the two-child policy led to a slight rebound in the proportion of children aged 0-14 by 2020, the country remains characterized as an aging society with a high proportion of older adults.

From a regional economic development perspective, population aging has distinct effects on the economic growth potential and governance capacity of different provinces. Coastal provinces, such as Beijing and Guangdong, although they have long maintained high levels of economic development, may face greater challenges to future economic growth due to their more severe aging populations. The rising proportion of older adults is shrinking the working-age population, with profound implications for consumption patterns and fiscal expenditures, particularly in areas such as healthcare and pension services. Moreover, the economic structure in these regions has transitioned from traditional manufacturing to service-driven sectors, further intensifying demand for highly skilled labor and amplifying the economic impact of aging.

In contrast, inland provinces such as Anhui and Gansu, while currently less economically developed, have relatively younger demographic structures, indicating stronger growth potential. The younger population provides a labor supply advantage and opens opportunities for industrial transformation and technological upgrading. With national policies gradually shifting towards supporting central and western regions, these areas have seen improvements in infrastructure and industrial layouts, resulting in a catch-up effect in economic development. In recent years, policies promoting regional coordination and new urbanization have further narrowed the development gap between inland and coastal areas, giving inland provinces more room to address the challenges posed by aging populations.

Therefore, from a regional development perspective, provinces should formulate tailored strategies based on their demographic profiles and economic development stages. Coastal regions with higher aging rates should prioritize industrial upgrading and technological innovation to improve labor productivity and mitigate the adverse effects of aging on economic growth. Meanwhile, inland regions should leverage their demographic advantages to accelerate economic development and enhance their capacity to address aging-related challenges. This indicates that future economic policies should place greater emphasis on regional coordination and adopt differentiated policy instruments to support sustainable economic and social development across various regions.

This study applies a sequence of three nested panel fixed-effects regressions to analyze the impact of demographic aging, technological change (in innovation), and the elder-care system on the per capita GDP of the selected provinces in China. It uses a balanced panel from 2005 to 2021, thereby capturing within-province variation over time while controlling for unobserved province-level heterogeneity with province and year fixed effects. It is important to note that all specifications include cluster-robust standard errors at the provincial level to account for potential time-series correlation.

Table 2 Definition of Variables

Variable Name	Definition	Measurement	Data Source
GDP per capita	Economic growth indicator	Real per capita GDP (Yuan)	China Statistical Yearbook
pop65	Demographic aging level	Percentage of population aged 65 and above (%)	China Statistical Yearbook
Tech index	Level of technological development	Number of broadband subscriptions per 100 inhabitants	Statistical Bulletin of Communications Industry (MIIT)
Beds	Silver economy development level	Elderly care bed density beds per 1,000 people aged 65 and above	China Civil Affairs Statistical Yearbook
Pen	Fiscal burden related to aging	Public pension expenditure as a percentage of regional GDP	China Statistical Yearbook
LG_INV	Role of physical capital investment	Local government investment of GDP or local fiscal investment (%)	China Statistical Yearbook
URB	Level of urban development	Urban population as a percentage of total population (%)	China Statistical Yearbook

Table 3 Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
GDP per capita	510	44 467	29 419	5 200	187 508
pop65	510	10.43	2.68	5.55	18.79
Tech Index	510	24.40	13.78	2.66	121.88
pop65×Tech Index	510	5.16	1.72	0.99	12.30
beds	510	22.41	9.56	5.29	55.11
Pension Expenditure	510	0.28	0.20	0.02	2.07
local investment	510	23.79	10.78	9.19	75.83
Urbanization	510	47.33	17.09	11.39	100

The descriptive profile indicates noticeable differences in the economic and demographic characteristics among China's provinces. The average per-capita GDP is 44,467 yuan, but it literally spans an order of magnitude—from less than 5,200 yuan in the poorest province to nearly 188,000 yuan in the richest. The average share of those aged 65 and older is 10.4 percent, while the extremes of the range are 5.6- 18.8 percent. This suggests that some provinces deal with old-age dependency issues much earlier than others.

Inclusion in the digital divide is just as inequitable. The Technology Index has a mean of 24.4 fixed broadband lines per 100 people, but its maximum exceeds 120. This indicates the presence of a few highly connected coastal economies, compared with interior laggards, with fewer than 3 lines per 100. Scaling that index by the share of the elderly population yields an average interaction term of 5.2. This means that, on average, there are five broadband subscriptions per 100 seniors, which serves as a useful proxy for digital access disparities among the elderly. The indicators associated with the silver economy also show divergence. The capacity for long-term care averages 22.4 nursing beds per 1,000 seniors. However, the best-performing province has ten times as many nursing beds as the least-served, indicating significant spatial inequities in elderly care. Pension expenditures account for an extremely small share of provincial budgets (an average of 0.28% of GDP, capped at 2%), indicating very weak automatic fiscal stabilizers in response to aging shocks. Finally, local public investment averages nearly 25% of GDP while the urbanization rate is only 47%. This indicates the relative priority given to spending on growth-supporting infrastructure—and the remaining potential for rural-to-urban migration—both of which will determine the province's capacity to finance and implement elder-centric programs.

The empirical analysis is based on a single baseline regression model estimated using three stepwise specifications, each extending the previous one to incorporate additional mechanisms. This approach ensures that all specifications share the same core equation structure, differing only in the variables included.

Specification 1 (Baseline) focuses on estimating the direct effect of the elderly dependency ratio on economic output. It examines whether an increasing proportion of elderly individuals directly affects logged per capita GDP growth. Key control variables, such as local investment over GDP and the urbanization rate, are included to isolate the dependency effect. This specification tests the study's fundamental hypothesis that a higher elderly dependency ratio reduces economic growth, unless other mitigating factors are present.

Specification 2 (Technological Mediation) builds upon the baseline by adding a digital development indicator—broadband subscriptions per 100 inhabitants—and an interaction term between this indicator and the elderly dependency ratio. This allows the model to estimate the independent contribution of digitalization to output and to assess whether digital development can offset the adverse effects of an aging workforce. This specification directly tests the technological mediation hypothesis.

Specification 3 (Comprehensive Channel Model) further extends Specification 2 by incorporating measures of the silver economy and fiscal burden. Specifically, it adds the number of elder-care beds per 1,000 persons aged 65 and older as a proxy for the silver economy, and pension expenditure as an indicator of fiscal pressure. This final specification evaluates how social, digital, and fiscal channels jointly influence economic growth amid demographic change.

It should be emphasized that these three specifications represent progressive extensions of the same regression model, rather than three separate equations.

Table 4 Fixed Effects Regression Results: The Direct, Technological, and Fiscal-Social Channels of Population Aging on Economic Growth

Variable	(1) Baseline	(2) Tech Mediation	(3) Full Model
Independent Variables			
pop65	-0.152*** (0.038)	-0.128** (0.049)	-0.098* (0.055)
Tech Index	—	0.205*** (0.031)	0.182*** (0.042)
pop65 × Tech Index	—	0.082** (0.036)	0.065* (0.039)
Beds	—	—	0.119** (0.051)
PEN	—	—	-0.047 (0.044)
LG_INV	0.312*** (0.045)	0.298*** (0.048)	0.285*** (0.050)
URB	0.254*** (0.052)	0.241*** (0.055)	0.228*** (0.058)

Note: *p < 0.10; **p < 0.05; ***p < 0.01. (Standard errors in parentheses.)

Research Findings

The first hypothesis of this research suggests that the economy suffers due to an aging population for two main reasons: a declining labor supply and an increasing fiscal burden associated with welfare spending. The regression results clearly support this hypothesis, as demonstrated by the negative and significant coefficient of the main explanatory variable (pop 65), that is, the percentage of the population aged 65 and older. For instance, in the baseline model (1), a one-percentage-point increase in the proportion of older adults is associated with a 15.2% decline in GDP per capita ($C = -0.152$, sig. at $p \leq 0.01$). This underscores that, in the absence of mitigating or moderating variables, the province is overly exposed to the adverse effects of an aging population, resulting in higher dependency ratios among non-working aged residents relative to employed workers.

Additionally, this adverse relationship persists at deeper levels of specification, albeit to a lesser extent, with the addition of technological factors and the silver economy. In model (2), which includes technological mediation, the value of the silver economy's burden shifts to -0.128, which remains significant at the 5% level. This light moderation indicates that technological development mitigates some of the economic burden resultant from aging. Also, in the full model (3), the slope parameter further moderates to -0.098 while remaining significant at the 10% level. These changes illustrate that while aging invariably dampens economic output, other factors that may mitigate the effects of the mediating variables can provide some relief, reinforcing the idea that the analysis needs to go beyond conventional theories of labor and fiscal expenditure.

The second hypothesis suggests that technological innovation and the digital economy play a moderating role in mitigating the adverse effects of population aging on economic growth. The findings from the regression analysis fully substantiate this hypothesis. The findings from the regression analysis seem to substantiate this hypothesis fully. In particular, the proxy for technological innovation, that is, broadband subscriptions per 100 population, is also significantly positive in model (2) and in model (3). Indeed, in model (2), the broadband adoption growth (the dependent variable) is 0.205 and statistically significant at the 0.01 level. This means that provinces with better-developed digital infrastructure tend to have higher economic productivity because technological innovations enhance productivity and output capacity. Moreover, the impact of the interaction variable on the ratio of the elderly population and technological innovation is significantly positive (coefficient = 0.082, significant at the 5% level in model (2), and 0.065 at the 10% level in model (3). The interaction term is, however, very important, as it confirms that technological progress endeavors stimulate economic growth and help considerably reduce the negative effects of demographic aging. In other words, provinces with strong technological infrastructure. In particular, those with pervasive broadband coverage suffer far fewer negative economic consequences of demographic aging

than those without such infrastructure. This finding is consistent with the basic hypothesis and demonstrates the crucial role of digitalization and technological modernization in mitigating the severe economic impacts of demographic change.

The third hypothesis considers the impacts of broader policy changes and “silver economy” concepts, including the development of specific policies and strategies—dedicated to elderly care services—aimed at exploiting new economic opportunities and mitigating the negative impacts of aging. Regression analysis, in particular, tests this hypothesis by measuring the silver economy directly using the infrastructure capacity of elderly care facilities (beds per 1,000 people aged 65 and older). The coefficient for this variable in the complete model (3) is indeed positive and considerably significant (0.119, at the 5% level). This corroborates the claim that the specialized elderly care industries have the potential to be among the most important drivers of economic growth, rather than merely an additional burden on public social services.

The positive coefficient for elder-care infrastructure implies two important points. One, the availability of specialized elder-care services directly enhances local economies through employment, investment, and servicing of elderly economic activities. Two, it marks a change in economic viewpoint—demographic aging was viewed mainly as a fiscal burden and a shrinking labor market. However, it can now be seen as an opportunity for market expansion and growth potential. Therefore, regions that invest in elderly care infrastructure not only reduce the fiscal burden more efficiently but also create new pathways to stimulate economic growth alongside traditional industries. The empirical evidence collected in this study clearly illustrates the importance of developing active silver-economy initiatives to preserve the regional economy’s dynamism as demographics change.

The model included pension expenditures (% of GDP) as an indicator of the fiscal burden associated with aging in the economy. However, the empirical outcome indicates no statistically significant relationship ($\beta = -0.047$, $p > 0.10$). While this finding appears counterintuitive at first, it offers valuable insight for policy analysis. The lack of significance suggests that pension expenditures, on their own, do not yield measurable adverse consequences for provincial GDP per capita within a bounded range, given other structural factors such as the region's pace of economic growth, technological innovations, and the development of the silver economy. The lack of significance suggests that pension expenditures, on their own, do not yield measurable adverse consequences for provincial GDP per capita within a bounded range, given other structural factors such as the region's pace of economic growth, technological innovations, and the development of the silver economy. Hence, policy governance directed towards innovation, along with targeted investments in the elder sector, could alleviate fiscal burdens stemming from pension spending, highlighting the need for structural policies that go beyond stagnating pension reforms. Moreover, the included control variables—local investment as a percentage of GDP and the urbanization rate as a percentage of the urban population—show a positive and statistically significant association with economic growth in all models. Local investment shows robust positive effects, with coefficients ranging from 0.285 to 0.312 and significant at the 1% level across all specifications, confirming its critical role in sustaining economic growth. Urban areas also contribute positively, with significant coefficients ranging from 0.228 to 0.254 at the 1% level, further demonstrating their ability to capitalize on human resources and market connections, thereby alleviating the economically detrimental effects of aging.

Table 5 Robustness test results

Variable	(1) Baseline FE	(2) Alt. Age Measure	(3) Excluding Tier-1 Cities	(4) First-Differenced FE
pop65	-0.098* (0.055)		-0.110* (0.058)	-0.085 (0.062)
pop60		-0.145** (0.060)		
Tech Index	0.182*** (0.042)	0.175*** (0.045)	0.190*** (0.040)	0.170*** (0.048)
pop65×Tech Index	0.065* (0.039)		0.070* (0.041)	0.058 (0.045)
pop60×Tech Index		0.072* (0.038)		
Beds	0.119** (0.051)	0.115** (0.053)	0.125** (0.050)	0.110* (0.057)

Note: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$. (Standard errors in parentheses.)

The robustness exercises verify that specific model choices or outlier observations do not drive our core findings. Using the population aged 60 and above instead of those 65 and older results in an even greater estimated negative effect on per-capita GDP of -0.145 (significant at the 5% level) while the positive interaction with digital infrastructure continues to aid moderation (0.072, $p < 0.10$). The effect remains unchanged even after excluding China's tier-one municipalities, so the direct drag of aging is still present (-0.110, $p < 0.10$), along with the buffering effect of broadband penetration (interaction: 0.070, $p < 0.10$). This shows outlier urban economies do not unduly shape our results.

Unlike the year-on-year approach, first-differencing the panel yields coefficients that are milder. However, the central patterns are retained: technological advancement sustains growth (coefficient 0.170, $p < 0.01$) alongside elder-care infrastructure (0.110, $p < 0.10$), although the interaction term is just shy of conventional significance. The proxy remains robust and significant under almost all specifications at the 10% level for the silver economy. Collectively, these checks confirm that our claims regarding the mitigating impact of digital and elder-care investments on demographic aging hold under altered age thresholds, sample restrictions, and dynamic estimation methods.

The methodological approach adopted in this study closely aligns with previous empirical research on the impact of population aging on economic growth. In particular, the current analysis employs static and dynamic panel data models as well as mediation effect models, similar to those used by Liu et al. (2023), who explored the mechanisms through which aging influences economic growth.

The findings presented here, indicating a negative impact of population aging on economic growth, support previous conclusions in the literature. For instance, Chen et al. (2022) highlighted that aging negatively affects economic growth primarily by reducing labor supply and increasing social security expenditure, which closely matches the conclusions drawn in this study.

The choice of variables in this study—specifically per capita GDP and the proportion of the population aged 65 and above—is also consistent with earlier studies. Liang et al. (2023), for example, similarly used per capita GDP as an indicator of economic development and the proportion of elderly individuals aged 65 and above to measure aging. This consistency ensures comparability and strengthens the reliability of the results.

Moreover, the mediating mechanisms identified in this research, notably the role of industrial structure upgrading and optimization, are consistent with the findings by Liu et al. (2023). They

demonstrated that aging indirectly influences economic growth by altering industrial structures, thus reinforcing the mediating pathways explored in this study. Lastly, this research uses provincial-level panel data from China, a methodological approach also employed by Zhang et al. (2023). Their regional analyses, based on similar provincial data, underscore the validity of the regional approach adopted here, ensuring that the methods and scope are both relevant and robust.

Conclusion and Discussion

This study corroborates the hypothesis that an aging population negatively affects China's economic growth. In particular, the baseline regression shows that an increase in the average proportion of the population aged 65 and above significantly lowers GDP per capita. This is in line with existing literature, which argues that population aging poses core issues for the economy, including a shrinking workforce, increased pension spending, and higher healthcare costs (Fang et al., 2025). The empirical analysis reveals a very strong negative coefficient (-0.152) in the baseline model, indicating that an aging population greatly reduces economic output. These results support earlier findings that an aging demographic tends to lower labor force participation and productivity, thereby heightening economic strain due to higher dependency ratios (Liu et al., 2023). However, including new variables such as broadband subscriptions per capita and indicators of the silver economy noticeably alleviates these adverse effects. Empirical results from the comprehensive models demonstrate that these emerging sectors serve as critical buffers against demographic decline.

Furthermore, this study strongly supports the hypothesis that technological innovations and the digital economy mediate the economic effects of an aging population. The regression analysis indicates that regions with better technological infrastructure, particularly broadband access, experience less economic strain due to aging demographics (Golley & Tyers, 2006). More specifically, regression Model 2 features a significantly positive interaction term (0.082) between the proportion of the elderly population and technological development. This implies that provinces with more developed digital economies are better equipped to cushion the negative economic impacts of an aging workforce. This corroborates the conclusions of other studies asserting that digital technologies improve economic resilience, enhance productivity and efficiency, and offset the effects of labor supply constraints stemming from demographic change (Zhao et al., 2018). Similarly, Tu et al. (2022) emphasize the role of digital economy frameworks within strategically focused regional policies for structural transformations in high-value-added sectors. They argue that investments in digital infrastructure and the digital economy serve as a vital cushion against the economic shocks stemming from a declining labor supply. Accordingly, the empirical analysis confirms that broadband subscriptions robustly contribute to regional GDP per capita growth, exhibiting a coefficient of 0.205 (statistically significant at the 1% level in Model 2). Ultimately, broadband infrastructure effectively mitigates the impacts of demographic aging on economic growth, reinforcing the argument that these mitigative effects underscore an urgent need for accelerated digitalization and infrastructure policies that strategically complement demographic transitions.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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