GOVERNANCE DIMENSION OF DEMOGRAPHIC CHANGE AND TECHNOLOGICAL ADVANCEMENT: THE IMPACT ON ECONOMIC GROWTH

Ngoc Mai La *, Quynh An Ngo **

* University of Canberra, Bruce, Australia; National Economics University, Hanoi, Vietnam
** *Corresponding author*, National Economics University, Hanoi, Vietnam.
Contact details: National Economics University, 207 Giai Phong road, Hai Ba Trung district, Hanoi 100000, Vietnam

OPEN ACCESS

How to cite this paper: La, N. M., & Ngo, Q. A. (2025). Governance dimension of demographic change and technological advancement: The impact on economic growth [Special issue]. *Journal of Governance and Regulation, 14*(4), 317–331. https://doi.org/10.22495/jgrv14i4siart9

ISSN Print: 2220-9352
ISSN Online: 2306-6784

Received: 24.02.2025
Revised: 21.05.2025; 05.06.2025; 29.10.2025
Accepted: 24.11.2025

JEL Classification: F43, J21, O47, P23, Q56
DOI: 10.22495/jgrv14i4siart9

Abstract

This research examines governance dimensions in the relationship between demographic change, technological advancement, and economic growth in Vietnam. Analyzing provincial data (2010–2019) by using generalized method of moments (GMM) estimation, we find that population aging positively impacts growth, challenging conventional demographic burden narratives (Bloom et al., 2003). Information and communication technology (ICT) adoption also contributes significantly to growth, extending previous findings on ICT's economic role. However, we identify a critical negative interaction between aging and ICT, with a calculated threshold (*age_ratio* = 0.39) where ICT's marginal impact becomes negative. These findings highlight both opportunities and challenges. The positive contribution of aging populations can be leveraged through governance mechanisms that capitalize on older workers' productivity, aligning with the "silver dividend" concept (Park & Shin, 2023). The negative interaction between aging and technology adoption, however, necessitates targeted governance approaches to bridge intergenerational digital divides. We propose a multidimensional governance framework integrating demographic and technological policies through coordinated institutional structures and regulatory mechanisms. This approach can help Vietnam maximize benefits from both demographic transition and technological advancement by mitigating negative interaction effects as the population ages, thereby transforming demographic challenges into opportunities for sustainable growth.

Keywords: Demographic Transition, Economic Growth, Governance Dimension, ICT Adoption, Technological Advancement, Vietnam

Authors' individual contribution: Conceptualization — N.M.L. and Q.A.N.; Methodology — N.M.L.; Validation —Q.A.N.; Writing — Review & Editing — Q.A.N. and N.M.L.; Visualization — N.M.L.

Declaration of conflicting interests: The Authors declare that there is no conflict of interest.

1. INTRODUCTION

Vietnam is navigating significant demographic and technological transitions, reshaping its socioeconomic landscape. Our study focuses on the period from 2010 to 2019, a crucial decade that captures Vietnam's accelerated development trajectory while offering several methodological advantages. Between 2010 and 2019, the ratio of the population aged 50 years old and above to those aged 20–49 years old increased steadily from 0.21 to 0.29, indicating a gradual population aging. Concurrently, Vietnam made remarkable strides in technological advancement, as evidenced by consistent improvements in the information and communication technology (ICT) index across provinces, albeit with significant regional variations.

The selection of this timeframe is deliberate and methodologically sound for several reasons. First, 2010 marks the beginning of comprehensive provincial-level ICT index data collection in Vietnam, providing a consistent baseline for measuring technological advancement. Second, this period represents a relatively stable phase of economic development, free from the extraordinary disruptions of the COVID-19 pandemic that began in 2020. Including post-2019 data would introduce significant distortions in both technological adoption patterns (due to sudden shifts to remote work and uneven digital infrastructure investments) and demographic behaviours (including migration reversals and altered family planning decisions). Third, this timeframe allows us to analyse the natural evolution of demographic and technological trends without the confounding effects of crisis-induced policy interventions.

These parallel trends of demographic shift and technological progress during 2010–2019 present both challenges and opportunities for Vietnam's continued economic growth and development. Understanding the interplay between demographic changes and technological progress is crucial for informed policymaking in Vietnam. As the country grapples with the economic implications of an aging population, it should also harness the potential of a technologically advanced workforce. Effective policies that address the needs of an aging population while promoting technological adoption across all age groups are essential for sustaining Vietnam's impressive growth trajectory.

Existing literature has extensively examined the relationships between demographic change, technological advancement, and economic growth. Studies by Bloom et al. (2003) and Bloom and Williamson (1998), and Kelley and Schmidt (2005) highlight the impact of demographic transitions on economic growth, particularly in East Asia. Czernich et al. (2011) and Waverman et al. (2005) demonstrate the positive effects of ICT adoption on economic growth, especially in developing countries. However, there is limited research specifically focusing on the Vietnamese context and the interaction between demographic shifts and technological progress in driving economic growth.

This research aims to analyze the relationship between population dynamics, technological progress, and economic growth in Vietnam, thereby proposing policy implications for effective governance of the interactions between these factors. Specifically, the study aims at three main objectives:

1) Determine the role of population aging and information technology applying to economic growth.

2) Identify and analyze the interactions between population aging and ICT on Vietnam's economic growth, focusing in particular on the threshold of population aging at which the impact of ICT on economic growth shifts from positive to negative.

3) The study will measure the individual impacts of population aging and ICT, as well as the interaction effects between them, to provide a practical basis for governance decisions.

4) Propose effective governance solutions to maximize economic benefits from both transitions — demographic and technological.

Based on the findings, the study provides several policy implications on managing the interaction between population aging and technology, focusing on how to maintain the positive impact of both determinants on economic growth in the context of Vietnam.

Our research contributes to the existing literature in several important ways. This study goes beyond the conventional analysis of the relationships between population dynamics, technological innovation, and economic growth. Notably, our results challenge the conventional view by finding a positive relationship between population aging and economic growth in Vietnam — a finding that contradicts many previous economic theories that suggest that population aging will hinder growth. While many policymakers and researchers are concerned about the negative impacts of "aging populations", our data indicate that at an early stage of the aging process, Vietnam may be benefiting from this demographic transition. This finding opens up new perspectives on how to leverage the changing demographics to drive economic growth, especially when combined with appropriate technological innovation strategies. We also provide empirical evidence on the role of ICT adoption in driving economic growth in the context of a rapidly developing Asian economy, extending the work of Vu (2011) into a more recent period. Third, we reveal a complex interaction between demographic changes and technological advancement, offering new insights into the challenges of promoting inclusive growth in the face of rapid demographic and technological transitions. In addition, the study also sheds light on the complex interactions between population aging and the adoption of ICT, highlighting the challenges in ensuring that older populations can access and benefit from the wave of digital transformation. Through this comprehensive analysis, we aim to provide a solid basis for policy decisions to maximize the benefits from both of the important transitions.

The research is structured as follows. Section 2 provides a detailed literature review. Section 3 describes the data and methodology, including the empirical strategy and model specifications. Section 4 presents the results and analysis, offering insights into the relationships between demographics, technology, and economic growth in Vietnam. Section 5 discusses the findings and their implications. Finally, Section 6 gives some conclusions and provides policy recommendations based on the findings.

2. LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Vietnam's rapid economic development over the past few decades has been accompanied by significant demographic shifts and technological advancements. Understanding the interplay between these factors is crucial for sustaining the country's growth trajectory. This review examines the literature on demographic change, ICT index, and economic growth, with a particular focus on Vietnam and similar developing economies.

2.1. Demographic change, information and communication technology, and economic growth

The relationship between population dynamics and economic growth has been extensively studied, with the theoretical foundation based on three main theories: the demographic dividend theory (Bloom et al., 2003), the life cycle hypothesis proposes that individual economic behaviour varies at different stages of life, affecting savings, consumption, and productivity (Ando & Modigliani, 1963), and the age-based productivity theory (Skirbekk, 2004). Bloom and Williamson (1998) found that age structure positively affects growth in East Asia when the working-age population grows faster than the dependent population, while An and Jeon (2006) found an inverted U-shaped relationship between the working-age population share and economic growth. According to the age-productivity profile theory suggests that productivity varies with age. Empirical research has employed increasingly sophisticated methods, from log-linear models to dynamic panel data models and instrumental variable methods (Acemoglu & Johnson, 2007), reflecting the increasing sophistication in understanding the relationship between population and growth.

The relationship between demographic change and economic growth has also been extensively studied in various contexts in the case of Vietnam or similar developing economies. Liao (2024) and the United Nations Population Fund (UNFPA, 2013) conducted a pivotal study projecting the country's demographic dividend. They estimated that Vietnam's demographic dividend would peak around 2009–2042 or 2015–2035, highlighting a crucial window of opportunity for economic growth. This finding underscores the urgency of implementing policies to capitalize on this demographic advantage before it begins to wane. Liao (2024) notes that Vietnam is aging before it modernizes, and that the governance framework needs to adjust to deal with challenges such as a shortage of skilled labor and weak infrastructure.

Expanding the scope to Southeast Asia, Ha and Chuah (2023) examine the impact of population aging on economic growth across the region. Their research revealed that while the demographic dividend in Southeast Asia is diminishing, it can be extended through appropriate policy interventions. This study provides valuable insights for countries like Vietnam, suggesting that proactive policies could help mitigate the economic challenges associated with an aging population.

These findings align with earlier global studies on the demographic dividend. For instance, Bloom et al. (2003) emphasise that changes in age structure can significantly boost economic growth when the working-age population grows faster than the dependent population. The projections for Vietnam by UNFPA (2013) and Liao (2024) suggest that the country is currently in this favourable demographic phase.

Regarding the impact of ICT on economic growth, research has demonstrated the positive role of ICT in various contexts. Czernich et al. (2011) found a positive relationship between broadband penetration and growth in Organisation for Economic Co-operation and Development (OECD) countries, while Waverman et al. (2005) showed that the impact of mobile telephony on growth is twice as large in developing countries as in developed countries. Röller and Waverman (2001) found a positive causal link between telecommunications infrastructure and economic growth, especially when a critical mass of infrastructure is reached.

In Vietnam, the role of ICT in driving economic growth has gained increasing attention, particularly in the context of developing economies. In a study specific to Vietnam, Vu (2011) investigates the contribution of ICT to the country's economic growth during the period 1996–2005. The study found that ICT contributed significantly to Vietnam's economic growth, with notable variations across different economic sectors. This research provides empirical evidence of the positive impact of technological advancement on Vietnam's economy, supporting the inclusion of ICT-related variables in models of economic growth for the country.

Vu's (2011) findings for Vietnam are consistent with broader studies on ICT and economic growth in developing countries. For instance, Waverman et al. (2005) demonstrate that mobile phones have a significant positive impact on economic growth, with the effect being twice as large in developing countries compared to developed ones. The significant contribution of ICT to Vietnam's growth, as found by Vu (2011), suggests that Vietnam's experience aligns with this broader trend in developing economies.

Based on the theoretical framework and literature review, we propose the following research hypotheses:

H1a: Population aging has a positive impact on economic growth in the early stages of the demographic transition in Vietnam.

H1b: The development and application of information and communication technology have a positive impact on economic growth in Vietnam.

2.2. Interaction information and communication technology, demographics, and economic growth

The interaction between ICT, demography, and economic growth is an emerging research area. Studies by Liu et al. (2024) and Czernich et al. (2011) developed a theory of the nonlinear relationship between technology and demographic factors. This theory proposes that the impact of technological progress on economic growth depends not only on the level of technology adoption but also on the demographic structure of the society, requiring the analysis of interaction effects. According to the age-based productivity theory (Skirbekk, 2004), labor efficiency tends to change over the life cycle, and the impact of technology on productivity may differ by age group. The digital divide theory (Van Dijk, 2006) also points out that access to and use of ICTs are uneven across population groups, especially between young and old populations.

Modern development economics models (Acemoglu & Restrepo, 2022) emphasize that population aging can promote automation and technological innovation as a compensatory mechanism. However, the effectiveness of this mechanism depends on the adaptability of the workforce. Previous empirical studies have shown a complex relationship between population aging and technology adoption. Frey (2011) found that countries with older populations often face more challenges in adopting new technology. However, countries with appropriate policies have been able to overcome this challenge, highlighting the importance of analyzing the interaction between aging and technology.

We, therefore, hypothesize the following interaction variable: We predict that the effect of ICT adoption on economic growth will vary with the age structure of the population. Specifically, we expect the positive impact of ICT on growth to decline as the proportion of older people (P50+/P20–49) increases, reflecting the potential challenges in ensuring that older populations can access and benefit from technological advances as effectively as younger populations.

Based on the theoretical framework, the hypothesis is designed as:

H2: There is a negative interaction between population aging and information and communication technology adoption on economic growth.

2.3. Governance of technological innovation in the context of demographic change

While studies have established the separate impacts of demographic change and ICT on economic growth, research on governance mechanisms for technological innovation in changing demographic contexts remains limited. Governance of technological innovation encompasses the institutional frameworks, policies, and regulatory mechanisms that guide technological development and adoption to maximize economic and social benefits. Effective governance structures are particularly crucial in navigating the complex interplay between technological advancement and demographic transitions.

In developed economies, several governance models have emerged to address technological adoption challenges among aging populations. For instance, Japan's "Society 5.0" framework presents a comprehensive governance approach that integrates technological innovation policies with aging population strategies (Harayama, 2017). This model demonstrates how strategic governance can transform demographic challenges into opportunities through targeted technology policies and regulatory frameworks that facilitate adoption across all age groups.

In developing economies, governance of technological innovation faces distinct challenges. Ha and Chuah (2023) highlight how governance structures in Southeast Asia economies often struggle to effectively coordinate ICT infrastructure development with human capital policies, limiting the potential economic benefits. This governance gap is particularly pronounced in contexts of rapid demographic change, where institutional frameworks may not adapt quickly enough to emerging challenges and opportunities.

The literature on governance mechanisms specific to Vietnam's technological development remains particularly sparse. While Vu (2011) quantified ICT's impact on Vietnam's economic growth, limited research exists on the governance structures that could optimize this relationship. This gap becomes especially significant considering Vietnam's rapid demographic transition and ambitious digital transformation goals. The effectiveness of Vietnam's technological governance will likely determine whether it can successfully leverage both its demographic transition and technological advancement for sustained economic growth.

Furthermore, the interaction between governance of technological innovation and demographic change introduces complex policy considerations. Effective governance requires not only promoting technological advancement but also ensuring equitable access across demographic groups through targeted policies and institutional mechanisms. As Liu et al. (2024) suggest, governance approaches that effectively integrate ICT development with demographic dividend utilization can potentially enhance economic outcomes beyond what either factor could achieve independently.

This research gap presents an opportunity to develop a more comprehensive understanding of how governance frameworks can be designed to maximize the economic benefits of technological innovation in the context of Vietnam's demographic transition. In the context of Vietnam, Liao (2024) forecast that the demographic dividend will peak around 2015–2035, highlighting the significant opportunity for economic growth. Vu (2011) found that ICT contributed significantly to Vietnam's economic growth during the period 1996–2005, with significant differences across economic sectors. The coincidence of the projected peak of the demographic dividend with the period of significant ICT contribution to growth suggests potential synergies between these factors, providing a unique opportunity to study how demographic change and technological progress together influence Vietnam's economic growth.

Röller and Waverman (2001) demonstrated the importance of "critical mass of infrastructure" in determining the impact of ICT on growth, suggesting the existence of thresholds. Combined with the nonlinear relationship theory of An and Jeon (2006) and Prskawetz et al. (2007), we can predict the existence of a critical threshold in the interaction between an aging population and ICT. Therefore, we can predict the existence of a critical threshold in the interaction between an aging population and ICT:

H3: There exists a critical threshold of the aging population at which the marginal impact of information and communication technology on economic growth changes from positive to negative.

Recent studies have expanded our understanding of the relationship between governance, demographic change, technological innovation, and economic growth.

Mazenda and Cheteni (2021) pointed out that an effective governance structure plays a crucial role in growth, sustainable development, and equitable income distribution (economic welfare) in their study of BRICS countries (Brazil, Russia, India, China, South Africa). Notably, the research found that countries with good governance principles do not necessarily deliver higher economic welfare outcomes, reflecting the importance of the right policies, especially in terms of structural transformation and equitable income distribution.

Regarding the role of innovation in growth, Shala et al. (2021) emphasized that technological innovation plays a key role in promoting economic development in emerging economies. The study found that innovative firms not only improve their own performance but also contribute to attracting foreign investment and improving the macroeconomic environment.

Besides, Priwarapan and Sonsuphap (2025) explored the linkages between green economy governance, clean technology, and sustainable development. The study proposes a strategic method, combining government incentives, public-private partnerships, and international cooperation, in line with the multidimensional governance framework needed to address complex challenges such as population aging and technological transition. In particular, the study highlights the importance of "continuous monitoring and adaptive management" — a key aspect in governing the interaction between population and technology.

Park et al. (2023) explored the relationship between population aging, the concept of "silver dividend", and economic growth in the context of Asian economies, especially the member countries of the Asian Development Bank (ADB). Drawing on data from Asian countries, the study assesses the impact of population aging — a widespread trend driven by declining fertility rates and increasing life expectancy — on economic growth and suggests ways to turn this challenge into an opportunity. The study finds that without adaptation, population aging could reduce gross domestic product (GDP) growth, mainly through a reduction in total factor productivity (TFP) growth. The "silver dividend" concept emphasizes that increasing the labor participation rate of older people (through technologies such as robots, artificial intelligence (AI), and supportive policies) can offset labor shortages. Research also shows that in countries with high human capital, long life expectancy, and high trade openness, the compensatory effect of higher labor participation rates implies that supportive policies and technologies play an important role.

Therefore, we expect that effective technology and population governance mechanisms can extend the duration of the demographic dividend by "continuous monitoring and adaptive management".

3. RESEARCH METHODOLOGY

In this section, we outline the data sources and methodology utilized in our study to investigate the relationships between demographic change, technological advancement, and economic growth in Vietnam from 2010 to 2019. Our analysis is based on provincial-level panel data, which provides a comprehensive overview of regional dynamics and enables statistical analysis.

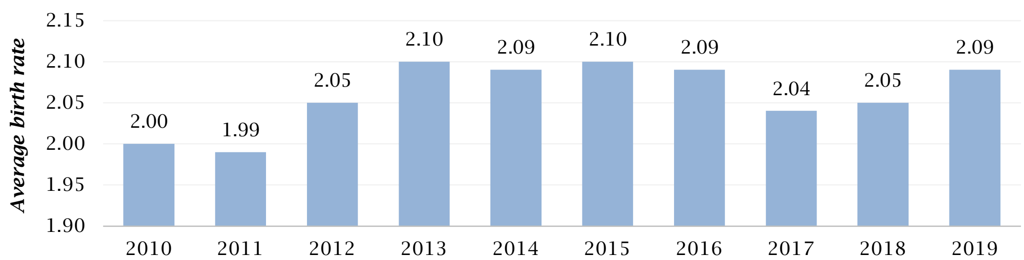
3.1. Data collection

This research utilizes a comprehensive dataset spanning from 2010 to 2019, encompassing key socioeconomic variables across various provinces in Vietnam. The data includes gross regional domestic product (GRDP) adjusted to 2010 prices in thousands of VND, birth rate per 1000 people, and a demographic ratio of the population aged 50 years old and above to those aged 20–49 years old. These economic and demographic indicators, sourced from the General Statistics Office of Vietnam, provide accurate data for analysing regional economic performance and population dynamics. Additionally, the dataset features an ICT development index, sourced from the Ministry of Information and Communications, which measures the level of ICT advancement across provinces. Each observation in the dataset is associated with a specific province, identified by both name and numeric code, and the year of observation, allowing for a detailed analysis of regional development dynamics over the decade.

3.1.1. Birth rate

The fluctuations in Vietnam's birth rate from 2010 to 2019, as shown in Figure 1, illustrate Vietnam's birth rate fluctuations from 2010 to 2019, reflecting a complex interplay of socio-economic, cultural, and policy factors, but remained around replacement fertility.

Figure 1. Average birth rate in Vietnam

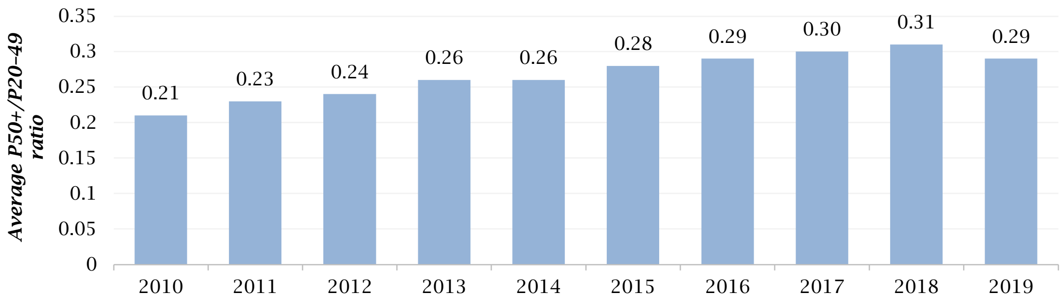


Source: Authors' elaboration based on the data of the General Statistics Office (https://shorturl.at/DuVgg).

3.1.2. Age ratio

Figure 2 depicts the ratio of the population aged 50+ years old to those aged 20–49 years old in Vietnam from 2010 to 2019. The ratio increased from 0.21 in 2010 to 0.31 in 2018, slightly declining to 0.29 in 2019. This trend reflects Vietnam's aging population, driven by improved healthcare and longer lifespans, coupled with declining birth rates from previous decades due to family planning policies and economic transitions. These factors have led to a larger proportion of older individuals in the population.

Figure 2. Average age ratio



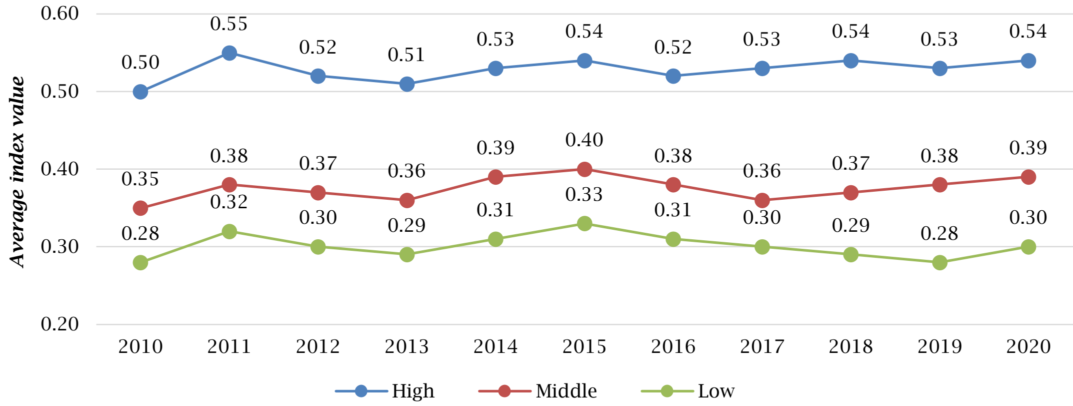
Source: Authors' elaboration.

This demographic shift presents both challenges and opportunities for Vietnam. While it may strain healthcare and social support systems, it also offers the potential to harness the experience of older generations. The slight decline in 2019 might be tied to a slight increase in fertility over the same period. Understanding these trends is crucial for developing policies that address the needs of an aging population while promoting sustainable development.

3.1.3. Information and communication technology index

The ICT index serves as a proxy for technological advancement in Vietnam. Figure 3 illustrates the variations in ICT development across provinces, categorized into high, middle, and low groups based on their ICT Index rankings.

Figure 3. Average information and communication technology index



Source: Authors' elaboration based on the reports on readiness index for development and application of information and communication technology in Vietnam for 2010–2020.

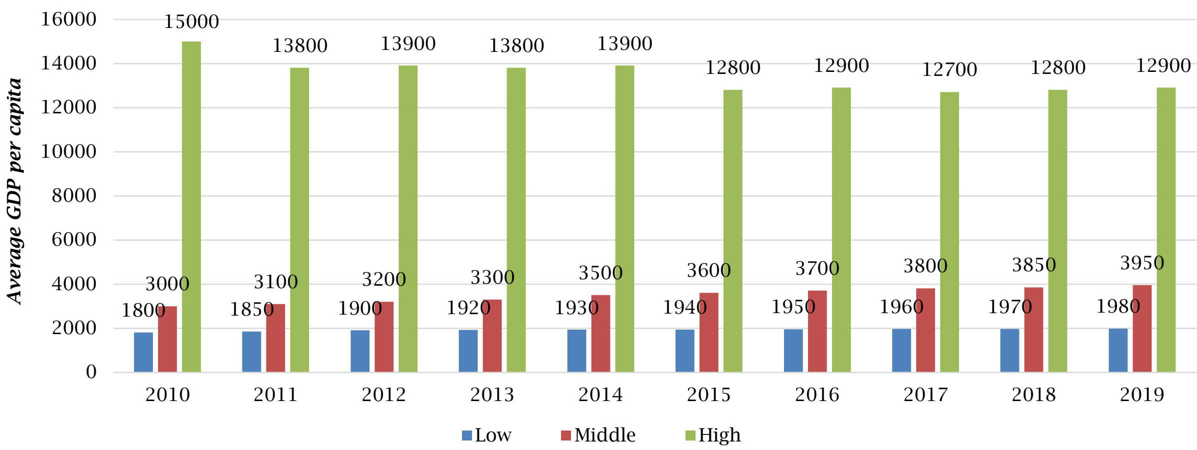
High-ranking provinces consistently show the highest average ICT Index values, with a significant peak around 2015, attributed to substantial investments in ICT infrastructure and education. The middle group exhibits a more fluctuating trend, stabilizing from 2015 onwards, likely due to targeted policy interventions and increased funding. Low-ranking provinces, despite lower overall values, demonstrate a general upward trend, particularly post-2015, indicating improvements in ICT infrastructure and usage across all regions.

While disparities in ICT development persist among Vietnamese provinces, all groups have shown growth and improvement, especially since 2015. This trend suggests that policies and investments aimed at enhancing ICT capabilities are yielding positive results across the board. Continued support for lower-ranking provinces could further reduce the digital divide and promote more balanced regional development in Vietnam.

3.1.4. Gross regional domestic product per capita

Figure 4 shows GRDP per capita trends across three groups of provinces. The high group (blue bars), likely including hubs like Ho Chi Minh City and Hanoi, consistently has the highest values, with steady growth driven by investments in infrastructure, industry, and technology, supported by favorable policies. The middle group (orange bars) shows moderate growth, improving through sector investments and technology, but hindered by limited infrastructure. The low group (green bars) has the lowest values yet displays a promising upward trend, fueled by targeted government initiatives and infrastructure improvements, though growth lags behind the other groups.

Figure 4. Average gross regional domestic product per capita (constant price 2010 thousands VND)



Source: Authors' elaboration.

Figure 4 highlights significant economic disparities among Vietnamese provinces, underscoring the need for policies addressing regional imbalances and promoting inclusive growth. Technological advancement plays a crucial role, as provinces with better access to technology and infrastructure tend to perform better economically. Enhancing technological capabilities across all provinces could help bridge these gaps and foster more uniform economic development.

3.2. Model specification and progression

Our study adopts a stepwise approach in model specification, starting from a core model based on fundamental economic growth theory and progressively incorporating demographic and technological factors. This approach allows us to systematically examine the individual and interactive effects of these variables on economic growth in Vietnam.

3.2.1. The core economic growth model

We begin with a basic economic growth model, drawing inspiration from the neoclassical growth framework (Solow, 1956) and its empirical applications (Barro, 1991). The core model is specified as:

$$ln\, Y_{it} = \beta_0 + \beta_1\, ln\, Y_{i(t-1)} + \varepsilon \quad (1)$$

where, $ln\, Y_{it}$ is the natural logarithm of GRDP per capita, constant price, province *i*, year *t*; $ln\, Y_{i(t-1)}$ is the lagged value of the dependent variable; and ε is the error term.

This specification captures the persistence in economic growth and allows for convergence effects, a key concept in growth literature (Islam, 1995). The use of panel data in economic growth estimation models offers several important advantages over simply using time series or cross-sectional data. Hsiao (2014) points out that panel data allows controlling for heterogeneity — unobserved province-specific characteristics — thereby minimizing bias due to missing important variables in the model. Baltagi (2021) adds that combining information across both space and time significantly increases the number of observations, improves the precision of the estimates, and reduces multicollinearity among explanatory variables. In addition, the use of panel data also helps to identify and measure effects that are difficult to observe when using cross-sectional data alone. Wooldridge (2010) points out that this is especially important in economic growth studies, where it is necessary to separate the effects of factors over time and space and to test the robustness of the economic relationships discovered.

In economic growth research, panel data also helps capture the dynamics of changes over time in policies and the adjustment process of macroeconomic variables. Bond (2002) emphasizes the ability to handle endogeneity by controlling for correlations between explanatory variables and errors, and allows the use of lag-based instrumental variables to mitigate reverse causality. Arellano and Bover (1995) further developed the generalized method of moments (GMM) estimation techniques that allow for maximum utilization of information from panel data to improve estimation efficiency. The GMM estimator to address endogeneity and capture the dynamics of economic growth has several advantages over alternative methods for this research.

Ordinary least squares (OLS) could be applied to estimate the relationship between GRDP per capita, demographic factors (age ratio, birth rate), and technological advancement (ICT index) using pooled cross-sectional data. This method is straightforward and effective for linear relationships, but it assumes strict exogeneity and does not account for unobserved heterogeneity across provinces or dynamic effects over time. Given the panel nature of our data and the presence of a lagged dependent variable, OLS would likely produce biased estimates, making GMM a more appropriate choice (Wooldridge, 2010).

A simpler fixed effects model without instrumental variables could be used to control for time-invariant province-specific characteristics. This approach is less computationally intensive than GMM and still addresses heterogeneity. However, it does not adequately handle endogeneity or reverse causality, particularly between ICT adoption and economic growth, which is why GMM was preferred (Bond, 2002).

3.2.2. Incorporating demographic factors

Building on the core model, we introduce demographic variables to capture the effects of population age structure and fertility on economic growth, as emphasized by Bloom and Williamson (1998):

$$ln\, Y_{it} = \beta_0 + \beta_1\, ln\, Y_{i(t-1)} + \beta_2 age\_ratio_{it} + \beta_3 birth\_rate_{it} + \varepsilon_{it} \quad (2)$$

where,

- age_ratio_{it} is the ratio of *P50+* to *P20-49* representing the age structure of the population in province *i*, year *t*. With the estimated results from the National Transfer Accounts (NTA) method, the surplus of labor productivity over the life cycle of Vietnamese people starts at age 22 years old and ends at age 56 years old (General Statistics Office & UNFPA, 2023), showing that the population group that contributes to Vietnam's economic growth is the population aged 22–56 years old, so we choose the ratio between the population aged 50 years old and over and the population aged 20–49 years old to represent the appropriate old-age dependency ratio.
- $birth\_rate_{it}$ captures fertility trends in province *i*, year *t*. The introduction of demographic variables into economic growth models is supported by both solid theoretical foundations and empirical evidence.

These two demographic variables affect economic growth through several mechanisms. The dependency ratio affects resources for investment and savings, labor supply and demand, public expenditure on social welfare, and average labor productivity. Meanwhile, the fertility rate is affected by investment in human capital, female labor force participation rate, care and education costs, and pressure on public resources. According to Modigliani and Brumberg (1954), the age-saving structure theory, the dependency ratio has an important impact on the economy's ability to save and invest. Mason (2007) points out that low dependency ratios create a "demographic opportunity" through increased resources for investment, while Bloom and Williamson (1998) clarify the impact of this variable on growth through changes in labor supply and demand. Empirical evidence from many studies also supports the role of these demographic variables. Kelley and Schmidt (1995) and Lee et al. (2003) provide evidence on the impact of dependency ratios in developing countries and Asia. Bloom et al. (2003) analyze in detail how the "Asian Tigers" exploited the demographic dividend for economic growth.

For birth rates, Notestein's (1953) demographic transition theory establishes a link between fertility and stages of economic development, complemented by Becker and Lewis's (1973) analysis of the relationship between fertility and investment in human capital. Regarding fertility rates, Barro (1991) demonstrates a strong relationship between fertility and GDP growth. This extension allows us to test hypotheses related to the demographic dividend and the economic impacts of population aging, key themes in our research.

The field has evolved methodologically over time. Early studies predominantly used log-linear models, with Bloom and Williamson (1998) employing such a model to study the impact of demographic transitions on economic growth in East Asia. Their findings indicated that changes in age structure accounted for approximately one-third of East Asia's economic miracle. Kelley and Schmidt (2005) extend this approach by incorporating both the levels and growth rates of age structure variables, providing a more comprehensive analysis of demographic effects.

As research progressed, non-linear relationships between demographic variables and economic growth were recognized. An and Jeon (2006) introduce quadratic terms to capture these non-linear effects, particularly focusing on the working-age population. Their study revealed an inverted U-shaped relationship between the proportion of the working-age population and economic growth. Building on this approach, Prskawetz et al. (2007) use a similar methodology but with more detailed age groups, identifying which specific age cohorts had the most significant impact on economic growth.

The advent of more sophisticated econometric techniques led to the widespread adoption of panel data approaches. Islam (1995) introduces dynamic panel data models to growth regressions, allowing for country-specific fixed effects and time effects. Addressing concerns of endogeneity, Acemoglu and Johnson (2007) employ an instrumental variable approach in a panel data context, using predicted mortality changes due to global health innovations as an instrument for life expectancy.

The literature consistently demonstrates that demographic changes have significant, often non-linear effects on economic growth. Most studies find a significant relationship between age structure and economic growth, with the effects often being non-linear (An & Jeon, 2006; Bloom et al., 2003). An increase in the working-age population is generally associated with higher economic growth but with diminishing returns (Kelley & Schmidt, 2005). Both youth and old-age dependency ratios are typically negatively associated with economic growth, although the magnitude and significance can vary across studies (Prskawetz et al., 2007). Lower birth rates are often associated with higher economic growth in the short to medium term, aligning with the demographic dividend theory (Bloom & Williamson, 1998).

The impact of increasing life expectancy on economic growth remains debated. While some studies find positive effects (Bloom et al., 2003), others report negative or insignificant effects (Acemoglu & Johnson, 2007), highlighting the complex nature of demographic-economic relationships and the importance of context-specific analysis.

3.2.3. Adding technological advancement

Recognizing the crucial role of technology in economic growth (Romer, 1990), we further extend our model to include an ICT index:

$$\ln Y_{it} = \beta_0 + \beta_1 \ln Y_{i(t-1)} + \beta_2 age\_ratio_{it} + \beta_3 birth\_rate_{it} + \beta_4 ICT\_index_{it} + \varepsilon_{it} \quad (3)$$

where, ICT_index_{it} is the ICT index in province *i*, year *t*.

This addition enables us to examine the direct impact of technological advancement on economic growth in Vietnam.

3.2.4. The final model with interaction effects

Finally, we introduce an interaction term between the age structure ratio and the ICT index. This specification is inspired by recent literature suggesting that the impact of demographic change on economic growth may be moderated by technological advancement. Liu et al. (2024) found that ICT development enhances the positive impact of the population dividend on economic growth, suggesting a synergistic relationship between technological progress and favourable demographic conditions. Acemoglu and Restrepo (2022) highlighted that population aging can promote automation and technological innovation as a compensatory mechanism, but the effectiveness depends on the adaptability of the older workforce. Park and Shin (2023) explore how technological progress can help prolong the demographic dividend through the concept of a "silver dividend". Qin and Xu (2024) discuss the interaction between the digital economy and the declining demographic dividend:

$$\ln Y_{it} = \beta_0 + \beta_1 \ln Y_{i(t-1)} + \beta_2 age\_ratio_{it} + \beta_3 birth\_rate_{it} + \beta_4 ICT\_index_{it} + \beta_5 age\_ratio_{it} \times ICT\_index_{it} + \varepsilon_{it} \quad (4)$$

Our study employs a sophisticated econometric framework to analyse the interplay between demographic change, technological advancement, and economic growth in Vietnam. The model's foundation is a log-linear specification inspired by Bloom and Williamson (1998), using the natural logarithm of *GRDP* per capita as the dependent variable to focus on proportional changes in economic output.

Key methodological features include:

- Dynamic panel techniques with a lagged dependent variable (Islam, 1995), capturing growth persistence and convergence effects.
- An interaction term between the age structure ratio and ICT index (An & Jeon, 2006) allows for potential non-linear relationships and synergies between demographic change and technological advancement.
- The GMM estimator (Arellano & Bond, 1991; Blundell & Bond, 1998) is used to address potential endogeneity.

This method employs lagged values of the endogenous variables as instruments, helping to isolate the causal effect of ICT development on economic growth.

This approach enables a systematic examination of the individual and combined effects of demographic change and technological advancement on Vietnam's economic growth. By integrating these methodological considerations, our model provides a comprehensive analysis of the factors driving Vietnam's economic growth, contributing to a deeper understanding of growth dynamics in developing economies undergoing rapid demographic and technological transitions.

4. RESULTS

Our empirical investigation yielded several significant findings that both corroborate and challenge previous research. We present these results and their interpretations, focusing on the interplay between Vietnam's demographic transition, technological progress, and economic growth.

Table 1 outlines key variables used to analyse economic growth, demographic changes, and technological advancements in Vietnam. The dependent variable, Y is the GRDP per capita at constant prices, sourced from the World Development Indicators, providing a measure of regional economic performance. The lagged GRDP per capita, $Y_{(t-1)}$, allows the analysis to account for past economic conditions.

Key independent variables include the age ratio (P50+/P20–49), birth rate, and ICT index. The age ratio, sourced from the General Statistics Office, captures the age structure of the population, indicating the proportion of older individuals relative to the working-age population. The birth rate, also from the General Statistics Office, measures fertility trends as the number of births per 1,000 people. The ICT index, provided by the Ministry of Information and Communications, serves as a proxy for technological advancement. These variables collectively enable a comprehensive analysis of how demographic shifts and technological progress influence economic growth in Vietnam.

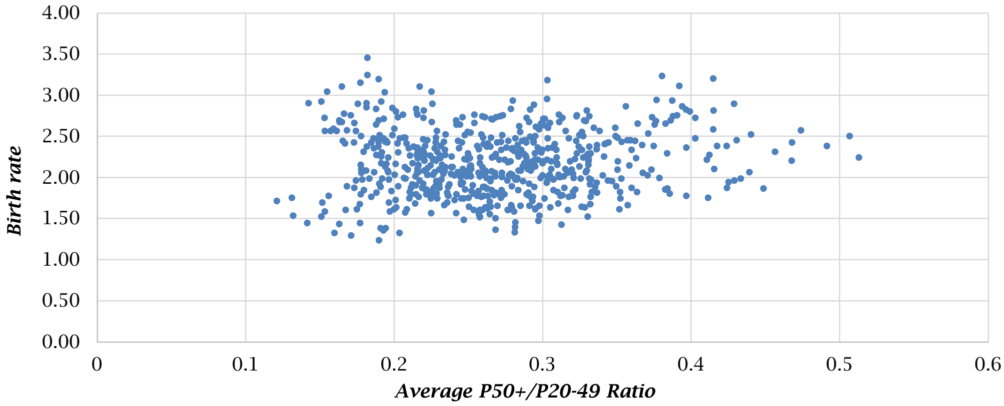
Table 1. Variables description

Variables	*Definition*	*Indicator description*	*Sources*
Y	GRDP per capita constant price	GRDP per capita (constant 2010 thousand VND)	World development indicators
Y_{t-1}	Lag GRDP per capita constant price	Lag GRDP per capita (constant 2010 thousand VND)	World development indicators
age_ratio	Represents the age structure of the population	P50+/P20-49	General Statistics Office
birth_rate	Captures fertility trends	birth rate per 1000 people	General Statistics Office
ICT_index	Technological change proxy	ICT index	Ministry of Information and Communications

Source: Authors' elaboration.

The dataset consists of 630 observations across several variables, including the age ratio and the birth rate. An initial inspection (Figure 5) confirmed that the data types and counts were appropriate for analysis. A pairwise correlation analysis revealed a coefficient of approximately 0.088 between the age ratio and the birth rate, indicating an almost negligible linear relationship between these variables. Further examination using the variance inflation factor (VIF) showed values of approximately 1.0079 for both predictors. Since VIF values near 1 suggest that there is no significant multicollinearity (with values above 5 or 10 typically considered problematic), it can be concluded that both the age ratio and the birth rate contribute independent information to the model. It is important to note that the high VIF value observed for the constant term (44.58) is expected and does not reflect an issue with multicollinearity.

Figure 5. Scatter plot of age ratio and birth rate



Source: Authors' elaboration.

The complex relationships between demographic changes, technological advancement, and economic growth in Vietnam, as captured in Eq. (4), necessitate a robust econometric approach. Our study employs the GMM estimation technique to address several methodological challenges inherent in our panel data analysis.

GMM offers significant advantages in handling potential endogeneity issues, which are likely to arise from the bidirectional relationship between key variables such as the ICT index and economic growth. Unlike standard estimation techniques, GMM provides consistent estimates by utilizing appropriate instrumental variables. This is particularly crucial for our model, which includes potentially endogenous variables like ICT_index_{it} and the interaction term ($age\_ratio_{it} \times ICT\_index_{it}$).

Our model's inclusion of a lagged dependent variable ($ln\ Yi_{(t-1)}$) introduces the risk of dynamic panel bias, especially given our relatively short time dimension (2010–2019). GMM is specifically designed to mitigate this bias, making it ideal for our analysis. Moreover, GMM is well-suited for panels with a short time dimension relative to the number of cross-sectional units, aligning perfectly with the structure of our dataset.

Another key advantage of GMM is its ability to account for both time-invariant and time-varying unobserved factors that might influence economic growth. This provides a more comprehensive analysis compared to standard fixed effects models, which are limited to controlling for time-invariant heterogeneity. Additionally, GMM's robustness to autocorrelation and heteroskedasticity, common issues in economic growth models, further justifies its application in our study.

We validate the robustness of our GMM estimation through post-estimation tests. The Arellano-Bond test for second-order autocorrelation (AR(2)) yields a p-value of 0.65, indicating no significant second-order autocorrelation in the differenced residuals. In addition, the Hansen test of overidentifying restrictions, with a p-value of 0.59, fails to reject the null hypothesis (H_0) of instrument validity, supporting the appropriateness of our instrument selection.

By employing GMM, we enhance the reliability and efficiency of our estimates, allowing for a more confident interpretation of the complex dynamics captured in Eq. (4). This methodological choice strengthens the credibility of our findings, particularly regarding the significant effects of the ICT index and the relationship revealed by the interaction between demographic factors and technological advancement in Vietnam's economic growth context.

Table 2. Impact of demographic change and technological change on gross regional domestic product per capita

Variables	***Dependent variable: ln Y_{it} (GRDP per capita)***			
	Pooling	***Fixed effects***	***Fixed effects + Year dummy***	***GMM***
Constant	0.613 (***)	1.22 (***)	2.369 (***)	1.505 (**)
age_ratio	0.04	0.183	0.035	0.694 (*)
birth_rate	-0.01	0.004	-0.032 (*)	-0.035(*)
ICT_index	0.199	0.042	0.024	0.758 (**)
Interaction	-0.32	-0.378	-0.117	-1.943 (*)
Lag ln $Y_{i(t-1)}$	0.94 (***)	0.861 (***)	0.718 (***)	0.798 (***)
Year_2012			-0.063 (**)	-0.0156
Year_2013			-0.039	-0.02
Year_2014			-0.003	-0.02 (*)
Year_2015			0.008	0.03
Year_2016			0.022	0.037
Year_2017			0.07	0.075 (*)
Year_2018			0.104	0.101 (*)
Year_2019			0.115	0.113 (*)
Observations	567	567	567	504
R-squared	0.98	0.979	0.962	
Pro > F	0.00	0.00	0.00	0.00
Sigma (u)		0.066	0.137	
Sigma e)		0.071	0.061	
Rho		0.463	0.834	
AR(2)				0.65
Hansen test				0.59

*Note: *, **, and *** represent significance level at 10%, 5%, and 1%, respectively.*
Source: Authors' elaboration.

Data in Table 2 offer significant insights into Vietnam's economic growth dynamics concerning demographic changes and technological advancement from 2010 to 2019. Across all models, the persistence of economic growth is evident, as indicated by the highly significant lagged GRDP per capita coefficients ranging from 0.718 to 0.94. This suggests that Vietnam's economic development has strong momentum, building upon previous years' achievements.

The GMM model, which addresses potential endogeneity issues, provides the most significant insights. The demographic ratio (P50+/P20–49) shows a positive (0.694) and marginally significant effect on growth. This finding challenges the conventional wisdom that an aging population necessarily hinders economic development. In Vietnam's case, it suggests that the older population may be contributing positively to the economy, possibly through increased savings, investment, or valuable workforce experience.

The ICT index emerges as a significant driver of economic growth in the GMM model, with a coefficient of 0.758, underscoring the importance of technological advancement in Vietnam's development trajectory. This aligns with the country's recent push towards digital transformation and Industry 4.0 initiatives. However, the negative interaction term (-1.943) between the demographic ratio and ICT index presents an intriguing dynamic. It implies that as the population ages, the positive impact of ICT on growth may be diminishing, highlighting a potential challenge for Vietnam in ensuring the benefits of technological progress are evenly distributed across all age groups.

The fixed effects model with year dummies reveals a marginally significant positive effect (0.032) of the birth rate on economic growth. This could be interpreted as evidence of Vietnam still benefiting from its demographic dividend. However, the slightly negative coefficient (-0.035) of the birth rate in the GMM model suggests that Vietnam may be transitioning to a stage where lower birth rates are associated with higher per capita growth, a pattern often seen in maturing economies.

The year dummy variables in both the fixed effects and GMM models show increasingly positive coefficients from 2015 onwards, with 2019 showing the highest positive impact (0.113 in GMM). This trend reflects Vietnam's robust economic performance in recent years, suggesting that the country's economic policies have been largely effective in promoting growth, even in the face of demographic shifts and technological adaptation challenges.

The model diagnostics support the validity of our analysis. The high R-squared values (0.98 in pooling, 0.979 in fixed effects) indicate strong explanatory power. The GMM model's AR(2) test (0.65) and Hansen test (0.59) suggest the model is well-specified and the instruments are valid.

The findings paint an obvious picture of Vietnam's economic growth dynamics. The country appears to be successfully leveraging both its demographic transition and technological advancements for economic gain. However, the findings also point to the need for targeted policies to ensure continued technological adoption across all age groups, particularly as the population ages. As Vietnam continues its development journey, balancing the opportunities and challenges presented by these demographic and technological shifts will be crucial for sustaining its impressive growth trajectory.

5. DISCUSSION

Our analysis of Vietnam's economic growth dynamics, based on a multi-year dataset, reveals a complex interplay between demographic changes, technological advancements, and economic development. The findings both support and challenge existing theories, offering new insights into the unique context of Vietnam's rapidly evolving economy. This discussion section will interpret our results, considering previous research and Vietnam's specific socio-economic conditions, exploring the implications for policy and future development strategies.

5.1. Demographic transition and economic growth

Examining the surprising relationship between population aging and economic growth, which challenges conventional wisdom, gives a deeper understanding of demographic transitions in developing economies. The positive (0.694) effect of the age ratio (P50+/P20–49) on GRDP per capita growth challenges conventional views on population aging. This aligns with (Bloom et al., 2003), suggesting that age structure changes can boost growth when managed effectively. This phenomenon can be explained through the following reasons:

Vietnam is currently in a special demographic transition period: it is enjoying a "golden population opportunity" with a high proportion of people of working age, and is also starting to experience population aging. In the early stages of this aging process, the population group over 50 years old is still quite active and contributes positively to the economy. According to the theory of demographic transition, before the aging population becomes a burden, there is a period when both the "young demographic dividend" and the "old demographic dividend" can coexist, creating a "double dividend". In Vietnam, this could also reflect accumulated savings of older individuals (Ando & Modigliani, 1963; Modigliani & Brumberg, 1954), continued workforce participation, or valuable experience in the economy.

The current population group over 50 years old has experienced the country's rapid economic development (since Doi Moi in 1986), allowing them to accumulate significant assets and savings. These resources are put into the financial system and reinvested in the economy, contributing to promoting growth. The population over 50 years old in Vietnam today possesses a significant capital of experience and professional skills, especially in the period of economic transition. Many of them have participated in the process of economic modernization and have accumulated valuable knowledge and experience.

Vietnam is characterized by a relatively high rate of older people continuing to participate in economic activities after the official retirement age, especially in the agricultural and informal sectors. According to the General Statistics Office and UNPFA (2023), many Vietnamese people over 50 years old are still working and contributing to production. This is different from many developed economies, where aging is often accompanied by high retirement rates.

In addition, there are interactions with institutional and policy factors. Vietnam's policies in recent years have begun to adapt to the trend of population aging, including reforming the pension system, expanding health insurance, and creating opportunities for the elderly to continue contributing to the economy. These policy changes may partly explain the positive relationship between the elderly population ratio and growth, especially in recent years (2017–2019) when the year dummies in the GMM model show an increasing positive impact.

The slightly negative birth rate coefficient (-0.035) indicates a transition to a stage where lower birth rates are associated with higher per capita growth, suggesting a shift towards productivity-driven expansion (Kelley & Schmidt, 2005). With characteristics of intergenerational wealth transfer and investment in the younger generation, in Vietnamese culture, the elderly often invest significantly in the education and development of their children and grandchildren. According to the quality-quantity theory of Becker and Lewis (1973), when the birth rate decreases (as seen in the negative coefficient of the *birth_rate* variable), families tend to invest more in the "quality" of each child, promoting human capital development. Elderly people in Vietnam often play an important role in financially supporting their children and grandchildren in education and starting a business, contributing to economic growth.

Regarding the interaction with technological development, although the results show a negative interaction between the proportion of the elderly population and the *ICT_index* (-1.943), the positive direct effects of the proportion of the elderly population (0.694) and the *ICT_index* (0.758) suggest that both factors are driving economic growth. The population over 50 years old may be contributing to growth through channels other than technology, such as managerial experience, relationship networks, and capital investment.

Finally, the cumulative growth effect with a high and statistically significant coefficient of the lagged variable GRDP per capita (0.798) in the GMM model shows the strong continuity of economic growth in Vietnam. This may be one mechanism through which the aging population positively impacts growth: the maintenance and enhancement of development achievements from previous generations.

In conclusion, the positive relationship between the proportion of the elderly population and economic growth in Vietnam is an important finding, challenging the traditional view. This can be explained by the characteristics of the demographic transition, the role of capital and experience accumulation, high labor participation rates, intergenerational wealth transfers, and interactions with appropriate institutional policies. However, the negative interaction with ICT warns of future challenges as Vietnam moves deeper into the process of population aging, requiring effective governance dimensions to maintain this positive relationship.

5.2. Technological advancement and economic growth

The ICT index significantly drives economic growth (coefficient 0.758), supporting Vu's (2011) findings and suggesting intensified impact in the recent decade. This aligns with Vietnam's digital transformation efforts (Waverman et al., 2005), showing ICT's pronounced effect in developing countries. It underscores ICT's potential to catalyse development and possibly bridge regional disparities, with Röller and Waverman (2001) suggesting increasing returns due to network effects.

5.3. Growth persistence and institutional factors

The high coefficient (0.798) of lagged ln GRDP per capita indicates strong growth persistence, aligning with Islam's (1995) dynamic panel models. This persistence likely reflects improved institutional quality, cumulative human capital effects, and reinforcing economic policies. It's particularly noteworthy given Vietnam's transition to a market-oriented economy, suggesting the successful establishment of growth-supporting institutions.

5.4. Interaction of demographics and technology

In the research model, the interaction variable ($age\_ratio_{it} \times ICT\_index_{it}$) has a coefficient of (-1.943) with statistical significance at the 10% level. The analytical value of this result is remarkable. The negative coefficient of the interaction variable shows that the effect of ICT on economic growth decreases as the proportion of the elderly population increases. Specifically, the marginal impact of ICT on growth is calculated as:

$$\frac{dlnY_{it}}{dICT\_index_{it}} = 0.758 - 1.943 \times age\_ratio_{it} \qquad (5)$$

This means that the positive effects of ICT will decrease as the proportion of the elderly population increases, and may even become negative when the proportion is high enough. The negative interaction suggests a governance challenge in ensuring that the benefits of technological innovation are distributed equitably across age groups. This result points to the urgent need for new governance dimensions to address the digital divide between generations.

Based on the coefficients of the variables, it is possible to calculate the optimal threshold of the elderly population ratio at which the marginal impact of ICT is zero or the "transition point" of the elderly population ratio (*age_ratio*) at which the impact of ICT on economic growth changes from positive to negative: $age\_ratio_{it} = 0.758 / 1.943 = 0.39$.

In which: 0.758 is the coefficient of the variable *ICT_index* (direct impact); -1.943 is the coefficient of the interaction variable ($age\_ratio \times ICT\_index$). This suggests that technology policy needs to be adjusted as the P50+/P20–49 ratio approaches this threshold to maintain the positive effect of ICT on growth. With an *age_ratio* of P50+/P20–49, a value of 0.39 means that when the population aged 50 and over is about 39% of the population aged 20–49, this is the equilibrium point for the effect of ICT.

- When *age_ratio* < 0.39: The marginal impact of ICT on economic growth is positive. This means that investment in ICT will boost economic growth.
- When *age_ratio* > 0.39: The marginal impact of ICT becomes negative. This means that investment in ICT may not have a positive effect on growth without additional governance measures.

5.5. Birth rate inconsistency and implications for Vietnam's demographic dividend phase

In the study results, a notable inconsistency appears related to the total fertility rate variable (*birth_rate*). Specifically, in different models, this variable shows coefficients with opposite signs:

- In the fixed effects model with year dummy variable: The coefficient of *birth_rate* is -0.032 with statistical significance at 10%.
- In the GMM model: The coefficient of *birth_rate* is -0.035 with statistical significance at 10%.
- However, in the analysis of the basic fixed effects model: The coefficient of *birth_rate* is 0.004 (not statistically significant).

This inconsistency, especially when controlling for fixed effects and endogeneity in the GMM model, requires a deeper analysis of the impact of birth rate on economic growth in Vietnam. Vietnam's provinces are at varying stages of demographic transition.

5.6. The implications of these for Vietnam's demographic dividend phase

Firstly, the negative birth rate coefficients in the GMM and fixed effects models with year dummy variables (-0.035 and -0.032) suggest that Vietnam may be in the transitional phase of the demographic dividend. According to the theory of the demographic dividend by Bloom and Williamson (1998), there are two main phases:

- Early phase: The decline in the birth rate leads to a decline in the child dependency ratio, creating a demographic dividend through an increase in the labor force to total population ratio.

• Later phase: As the birth rate continues to decline, the working-age population begins to age, changing the structure of savings and investment, and the impact of the decline in the birth rate becomes more complex.

Secondly, the negative coefficient of the *birth_rate* variable in the advanced models suggests that Vietnam may be at a stage where the benefits of lower fertility rates (lower dependency ratio, increased savings rate) outweigh the potential costs (reduced future young workforce).

In addition, having both a positive *age_ratio* coefficient (0.694) and a negative *birth_rate* coefficient (-0.035) in the same GMM model shows an interesting picture of the interaction between demographic variables:

1) Increasing proportion of elderly: Positive impact on growth (possibly through savings, investment, experience).

2) Declining birth rate: Also a positive impact on growth (through reduced dependency ratio, increased investment in human capital per child).

This suggests that Vietnam is in a "dual window of opportunity" — benefiting from both a falling birth rate and an early period of aging population.

Besides, the discrepancy between the models may reflect the fact that different regions of Vietnam are at different stages of the demographic dividend. Some provinces may still be in the early stages (where higher fertility rates are still beneficial to growth through the supply of young workers), while others have moved to the later stages (where lower fertility rates are beneficial to growth through capital accumulation and investment in quality).

Finally, in the context of declining fertility rates and increasing proportions of the elderly, the interaction with ICT becomes particularly important. The negative interaction coefficient between *age_ratio* and *ICT_index* (-1.943) illustrates the challenge of linking technological progress with an aging population. This becomes even more important given the trend of declining fertility rates, which will increase the proportion of the elderly in the future.

6. CONCLUSION

This research provides comprehensive insights into the governance dimensions of demographic change and technological advancement, and their impact on economic growth in Vietnam. Our empirical analysis yields several important findings with significant implications for policy and theory.

Firstly, population aging demonstrates a positive impact on economic growth during the early stages of demographic transition in Vietnam. The GMM model reveals a positive coefficient (0.694) for the age ratio (P50+/P20–49), indicating that Vietnam's current demographic transition phase benefits from its aging population's contribution to economic growth. This challenges conventional wisdom that population aging necessarily hinders economic development. The positive relationship likely stems from higher education levels, accumulated experience, and savings of Vietnam's older population during this early aging stage.

Secondly, the development and application of ICT significantly enhance economic growth in Vietnam. The ICT index emerges as a robust growth driver with a positive coefficient (0.758) in the GMM model, confirming that investments in ICT substantially contribute to Vietnam's economic expansion. This finding aligns with previous research by Vu (2011) and underscores the critical role of digital transformation in Vietnam's development trajectory.

Thirdly, a negative interaction exists between population aging and ICT adoption regarding economic growth. The interaction term between age ratio and ICT index shows a significant negative coefficient (-1.943), revealing complex dynamics between demographic change and technological advancement. This indicates that as populations age, ICT's positive growth impact diminishes, with our analysis identifying a critical threshold age ratio of 0.39 where ICT's marginal effect becomes negative.

Additionally, our findings on the birth rate's inconsistent impact across different model specifications suggest that Vietnam's provinces may be at varying stages of demographic transition, requiring differentiated governance approaches.

These findings have implications for Vietnam's economic governance and policy framework. The positive individual effects of both demographic change and ICT adoption suggest that Vietnam is well — positioned to leverage both demographic dividends and technological advancement. However, the negative interaction effect highlights the urgent need for integrated governance approaches that ensure equitable technology adoption across age groups and prevent the marginalization of older populations in digital transformation processes.

The identification of the critical threshold (*age_ratio* = 0.39) provides policymakers with an actionable benchmark for implementing targeted interventions. This suggests that governance strategies must be proactive rather than reactive, implementing age-inclusive technology policies before reaching this critical demographic composition.

Furthermore, the varying impact of birth rates across model specifications indicates that Vietnam's provinces are at different stages of demographic transition, necessitating differentiated governance approaches that account for regional demographic diversity. The significant positive year effects from 2017–2019 suggest that governance effectiveness has improved during this period, providing a foundation for continued policy innovation. The results may be applicable to other developing countries with similar demographic and technological contexts to those of other Southeast Asian nations or emerging economies.

Several limitations constrain the generalizability and scope of our findings. Firstly, our analysis relies on provincial-level aggregate data, which may mask important intra-provincial variations and individual-level dynamics that could provide deeper insights into the mechanisms driving the observed relationships. The aggregation level prevents examination of firm-level or household-level responses to demographic and technological changes.

Secondly, the ICT index, while comprehensive, may not capture all dimensions of technological advancement, particularly emerging technologies like AI, blockchain, or Internet of Things (IoT) applications that are increasingly relevant to economic growth. The index may also suffer from measurement bias in regions with limited digital infrastructure.

Thirdly, the study period (2010–2020) encompasses both stable growth periods and economic disruptions, but may not adequately capture long-term demographic trends that unfold over decades. The COVID-19 pandemic's impact on the final year of analysis may also introduce temporary distortions that affect long-term trend interpretation.

Future research should address these limitations through several directions. First, micro-level analysis using firm-level or household-level data would provide deeper insights into the mechanisms through which demographic change and ICT adoption interact to influence economic outcomes. Such research could examine how different age cohorts within organizations or communities respond to technological changes.

Second, longitudinal studies spanning longer time periods would better capture the full demographic transition process and provide more robust evidence on the sustainability of positive aging effects. Panel studies following specific cohorts over time would be particularly valuable.

Third, research should explore the role of specific governance interventions in moderating the negative interaction between aging and ICT adoption. Experimental or quasi-experimental designs could evaluate the effectiveness of different policy approaches to promoting age-inclusive technology adoption.

Fourth, future studies should incorporate broader measures of technological advancement, including AI adoption, digital literacy programs, and smart city initiatives, to provide a more comprehensive understanding of technology's role in economic development.

Finally, research should examine the social and environmental dimensions of the demographic-technology-growth nexus, investigating how governance frameworks can simultaneously address economic growth, social equity, and environmental sustainability in the context of demographic transitions.

Our methodological innovations, including the development of a comprehensive governance framework integrating demographic transition and technological change management, provide a foundation for these future research directions. The application of panel analysis with GMM techniques offers a template for addressing endogeneity and heterogeneity issues in similar studies, while our composite ICT index approach demonstrates how multiple dimensions of technological adoption can be systematically incorporated into growth analysis.

Based on the findings, we propose the following governance-focused policy recommendations:

We recommend implementing a "threshold-based governance framework", an adaptive governance system based on the proximity of each province's age ratio to the critical threshold of 0.39. Provinces should be classified into three categories:

- Those far from the threshold (*age_ratio* < 0.25): Focus on regular ICT investments to maximize positive growth impacts
- Those approaching the threshold (0.25 ≤ *age_ratio* < 0.35): Implement combined strategies of ICT investment and digital skills programs for older adults
- Those at or near the threshold (*age_ratio* ≥ 0.35): Establish specialized coordination mechanisms between population and information technology governance bodies.

To address the negative interaction between population aging and ICT, it should be establishing a multi-dimensional governance mechanism with the National Coordination Committee on Population and Digital Technology to formalize policy coordination between population management and ICT agencies. This committee should implement: 1) mandatory cross-impact assessments for all technology and population policies; 2) integrated performance metrics that measure success across both demographic and technological dimensions; 3) joint planning processes for digital transformation and demographic management initiatives; 4) age-inclusive technology governance (establishing national standards and regulatory frameworks for age-inclusive design in digital services; creating incentive structures (tax benefits, research grants) for developing technologies specifically designed for older adults; implementing community-level digital support networks with governance oversight to ensure accessibility and effectiveness for all people).

The variations in our model results suggest the need for geographically differentiated governance structures: 1) developing a comprehensive mapping of both population aging patterns and technology adoption rates at the provincial level; 2) implementing regionally customized ICT governance strategies based on demographic profiles; 3) allocating resources through governance structures that account for both current demographic status and projected transitions.

The positive coefficient of *age_ratio* combined with the negative interaction with ICT points to the need for human capital governance integration strategies: developing governance frameworks for age-specific digital skills training; establishing certification systems for "second-career" digital skills; and creating governance mechanisms for cross-generational knowledge transfer.

REFERENCES

Acemoglu, D., & Johnson, S. (2007). Disease and development: The effect of life expectancy on economic growth. *Journal of Political Economy, 115*(6), 925–985. https://doi.org/10.1086/529000

Acemoglu, D., & Restrepo, P. (2022). Demographics and automation. *The Review of Economic Studies, 89*(1), 1–44. https://doi.org/10.1093/restud/rdab031

An, C.-B., & Jeon, S.-H. (2006). Demographic change and economic growth: An inverted-U shape relationship. *Economics Letters, 92*(3), 447–454. https://doi.org/10.1016/j.econlet.2006.03.030

Ando, A., & Modigliani, F. (1963). The "life cycle" hypothesis of saving: Aggregate implications and tests. *The American Economic Review, 53*(1), 55–84. https://www.jstor.org/stable/1817129

Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The Review of Economic Studies, 58*(2), 277–297. https://doi.org/10.2307/2297968

Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-component models. *Journal of Econometrics, 68*(1), 29–51. https://doi.org/10.1016/0304-4076(94)01642-D

Baltagi, B. (2021). *Econometric analysis of panel data*. Springer.

Barro, R. J. (1991). Economic growth in a cross section of countries. *The Quarterly Journal of Economics, 106*(2), 407–443. https://doi.org/10.2307/2937943
Becker, G. S., & Lewis, H. G. (1973). On the interaction between the quantity and quality of children. *Journal of Political Economy, 81*(2), 279–288. https://doi.org/10.1086/260166
Bloom, D. E., & Williamson, J. G. (1998). Demographic transitions and economic miracles in emerging Asia. *The World Bank Economic Review, 12*(3), 419–455. https://doi.org/10.1093/wber/12.3.419
Bloom, D. E., Canning, D., & Sevilla, J. (2003). *The demographic dividend: A new perspective on the economic consequences of population change.* RAND Corporation. https://doi.org/10.7249/MR1274
Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics, 87*(1), 115–143. https://doi.org/10.1016/S0304-4076(98)00009-8
Bond, S. R. (2002). Dynamic panel data models: A guide to micro data methods and practice. *Portuguese Economic Journal, 1*, 141–162. https://doi.org/10.1007/s10258-002-0009-9
Czernich, N., Falck, O., Kretschmer, T., & Woessmann, L. (2011). Broadband infrastructure and economic growth. *The Economic Journal, 121*(552), 505–532. https://doi.org/10.1111/j.1468-0297.2011.02420.x
Frey, C. B. (2011). *The technology trap: Capital, labor, and power in the age of automation.* Princeton University Press.
General Statistics Office, & United Nations Population Fund (UNFPA). (2023, December 6). *Overview on Viet Nam National Transfer Accounts: Key findings and policy implications.* https://vietnam.unfpa.org/en/publications/overview-viet-nam-national-transfer-accounts-key-findings-and-policy-implications
Ha, H., & Chuah, C. K. P. (2023). Digital economy in Southeast Asia: Challenges, opportunities and future development. *Southeast Asia: A Multidisciplinary Journal, 23*(1), 19–35. https://doi.org/10.1108/SEAMJ-02-2023-0023
Harayama, Y. (2017). Society 5.0: Aiming for a new human-centered society: Japan's science and technology policies for addressing global social challenges. *Hitachi Review, 66*(6), 554–555. https://www.hitachihyoron.com/rev/archive/2017/r2017_06/trends/index.html
Hsiao, C. (2014). *Analysis of panel data.* Cambridge University Press.
Islam, M. (1995). *Constitutional law of Bangladesh* (Vol. 90). Springer.
Kelley, A. C., & Schmidt, R. M. (1995). Aggregate population and economic growth correlations: The role of the components of demographic change. *Demography, 32*(4), 543–555. https://doi.org/10.2307/2061674
Kelley, A. C., & Schmidt, R. M. (2005). Evolution of recent economic-demographic modeling: A synthesis. *Journal of Population Economics, 18*, 275–300. https://doi.org/10.1007/s00148-005-0222-9
Lee, R., Mason, A., & Miller, T. (2003). Saving, wealth and the transition from transfers to individual responsibility: The cases of Taiwan and the United States. *The Scandinavian Journal of Economics, 105*(3), 339–358. https://doi.org/10.1111/1467-9442.t01-2-00002
Liao, R. (2024). Research on Vietnam's demographic dividend period. *Communications in Humanities Research, 34*(1), 128–133. https://doi.org/10.54254/2753-7064/34/20240125
Liu, X., Qin, C., Liu, B., Ahmed, A. D., Ding, C. J., & Huang, Y. (2024). The economic and environmental dividends of the digital development strategy: Evidence from Chinese cities. *Journal of Cleaner Production, 440*, Article 140398. https://doi.org/10.1016/j.jclepro.2023.140398
Mason, A. (2007). Demographic transition and demographic dividends in developed and developing countries. In *United Nations Expert Group Meeting on Social, & Economic Implications of Changing Population Age Structures* (pp. 81–101). UN. Population Division. https://digitallibrary.un.org/record/3924650?v=pdf
Mazenda, A., & Cheteni, P. (2021). Governance and economic welfare: A BRICS panel analysis. *Journal of Governance & Regulation, 10*(2), 290–299. https://doi.org/10.22495/jgrv10i2siart9
Modigliani, F., & Brumberg, R. H. (1954). Utility analysis and the consumption function: An interpretation of cross-section data. In K. K. Kurihara (Ed.), *Post-Keynesian economics* (pp. 388–436). Rutgers University Press.
Notestein, F. W. (1953). Economic problems of population change. In *Proceedings of the 8th International Conference of Agricultural Economists* (pp. 13–31). Oxford University Press.
Park, D., & Shin, K. (2023). *Population aging, silver dividend, and economic growth* (Working Paper No. 678). Asian Development Bank (ADB). https://doi.org/10.2139/ssrn.4381806
Priwarapan, S., & Sonsuphap, R. (2025). Green economy governance and regulation: Green industry and clean technology for sustainable development. *Corporate Governance and Sustainability Review, 9*(2), 8–17. https://doi.org/10.22495/cgsrv9i2p1
Prskawetz, A., Fent, T., Barthel, W., Crespo-Cuaresma, J., Lindh, T., Malmberg, B., & Halvarsson, M. (2007). *The relationship between demographic change and economic growth in the EU* (Report for Tender VT/2005/035). Vienna Institute of Demography. https://www.oeaw.ac.at/fileadmin/subsites/Institute/VID/PDF/Publications/Forschungsberichte/FB32.pdf
Qin, J., & Xu, Q. (2024). The impact of the digital economy on population dividends in China: Based on the dual perspective of quantity and quality. *Sustainability, 16*(10), Article 4254. https://doi.org/10.3390/su16104254
Röller, L.-H., & Waverman, L. (2001). Telecommunications infrastructure and economic development: A simultaneous approach. *American Economic Review, 91*(4), 909–923. https://doi.org/10.1257/aer.91.4.909
Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy, 98*(5, Part 2), 71–102. https://doi.org/10.1086/261725
Shala, V., Bytyçi, S., & Dodaj, P. (2021). The role of innovation in the growth of the company: A case of the emerging country. *Journal of Governance & Regulation, 10*(4), 175–182. https://doi.org/10.22495/jgrv10i4art16
Skirbekk, V. (2004). Age and individual productivity: A literature survey. *Vienna Yearbook of Population Research*, 133–153. https://doi.org/10.1553/populationyearbook2004s133
Solow, R. M. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics, 70*(1), 65–94. https://doi.org/10.2307/1884513
United Nations Population Fund (UNFPA). (2013). *Population and development in Viet Nam: Towards a new strategy 2011–2020* (Code: GEN–304). https://www.unfpa.org/sites/default/files/resource-pdf/brief_srb_en.pdf
Van Dijk, J. A. (2006). Digital divide research, achievements and shortcomings. *Poetics, 34*(4–5), 221–235. https://doi.org/10.1016/j.poetic.2006.05.004
Vu, K. M. (2011). ICT as a source of economic growth in the information age: Empirical evidence from the 1996–2005 period. *Telecommunications Policy, 35*(4), 357–372. https://doi.org/10.1016/j.telpol.2011.02.008
Waverman, L., Meschi, M., & Fuss, M. (2005). *The impact of telecoms on economic growth in developing countries.* https://www.assignmentpoint.com/wp-content/uploads/2012/04/L_Waverman_Telecoms_Growth_in_Dev_Countries.pdf
Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data.* MIT Press.