

Ageing Populations and Labour Productivity: A Comparative Panel Data Analysis

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Abstract

This dissertation investigates how demographic ageing affects labour productivity, using panel data from 29 developed and 8 developing countries between 1997 and 2022. With populations ageing due to longer life expectancies and declining fertility, understanding the economic impact is increasingly important. Unlike much existing research that focuses on GDP growth, this study emphasises labour productivity, measured as GDP per person employed, to capture workforce efficiency and human capital use. The analysis explores both linear and non-linear effects of ageing, alongside structural factors such as public health, institutional quality, innovation, and capital investment. Fixed effects models are applied to the full and individual samples. Results for developed economies indicate a statistically significant inverted U-shaped relationship: moderate ageing may enhance productivity through experience accumulation before dependency burdens reduce it. In contrast, developing economies show no significant relationship, likely reflecting earlier stages of demographic transition or structural barriers. Structural drivers also differ by context. In developed economies, productivity is positively associated with life expectancy, governance, and capital investment, though innovation shows diminishing returns. In developing economies, life expectancy matters, but governance, capital, and R&D exert weaker effects, highlighting capacity constraints. These findings pose important implications for policymakers. Advanced economies must support older workers through health investment, flexible retirement, and lifelong learning. Developing countries should focus on strengthening structural foundations to productively harness future demographic change. Ageing's impact ultimately depends on how effectively countries adapt through policy, investment, and institutions.

AI Statement

I acknowledge the use of generative AI in drafting this paper. However, the work reported remains my own.

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1 Introduction

Demographic patterns worldwide are shifting dramatically. Advances in healthcare and living conditions have contributed to a sharp rise in life expectancy, while fertility rates have steadily declined. Since 1960, global life expectancy has increased by over 23 years for those born in 2021 (Datanni et al., 2023), and fertility rates have fallen by half (World Economic Forum, 2022). These trends are accelerating the ageing of the global population. According to the United Nations (2024), the number of people aged 65 and over is projected to surpass the number of children under 18 by the late 2070s, reaching 2.2 billion by 2080. In some regions, those aged 80 and above will outnumber infants by the mid-2030s. As this shift continues, nearly one in four people globally will be aged 65 or over by the end of the century (United Nations, 2024), raising fundamental questions about how economies will adapt to a smaller working-age population and a growing share of older adults.

This shift poses complex challenges for labour markets and future economic performance. Shrinking workforces and rising dependency ratios risk undermining countries' ability to sustain innovation, competitiveness, and rising living standards. While older populations bring valuable experience, they are also more likely to face health limitations, outdated skills, and lower labour force participation (Lucas, 1988), all of which may constrain the effective use of human capital.

Despite growing interest in the economic implications of ageing, much of the existing literature centres on growth rather than productivity. This study shifts the focus to labour productivity, offering a more direct lens on workforce efficiency in the context of demographic change. It investigates how ageing influences productivity across developed and developing countries and considers how this relationship may be shaped by broader structural conditions such as investment levels, governance quality, and health outcomes.

The analysis addresses three core questions:

1. What is the relationship between demographic ageing and labour productivity?
2. Does this relationship differ systematically between developed and developing economies?
3. To what extent do structural factors shape the ageing-productivity relationship?

To investigate these questions, this paper employs panel data covering countries at different stages of demographic transition. It tests for both linear and non-linear effects of ageing, alongside interactions with structural variables. In doing so, it provides new evidence for policymakers navigating the economic challenges of population ageing.

2 Literature Review

2.1 Economic Theory

Long-term economic performance is driven largely by productivity. Demographic change, particularly population ageing, raises fundamental questions about whether these gains can be sustained as the workforce shrinks and ages. As the share of older individuals increases, both the quality and quantity of labour inputs evolve, influencing capital accumulation, saving behaviour, and the capacity for innovation (Beaudry, et al., 2005). While some theoretical models suggest ageing may enhance productivity through accumulated experience and capital deepening, others emphasise the risks posed by reduced labour force participation and slower technological adoption. This section reviews neoclassical growth theory and life-cycle models, two key theoretical frameworks, to explore how ageing interacts with productivity.

2.1.1 Neoclassical Growth Theory

The Solow model provides a foundational framework for analysing long-run economic growth by linking output to capital accumulation, labour input, and technological progress. It assumes constant returns to scale, diminishing marginal returns to individual factors, and exogenous technological progress meaning innovation is determined outside the model and does not respond to economic or demographic forces (Solow, 1956).

The model is typically expressed using an output per-worker production function:

$$y = k^{\alpha}$$

Where y is output per worker, k is capital per worker, and $\alpha \in (0, 1)$ is the elasticity of output with respect to capital.

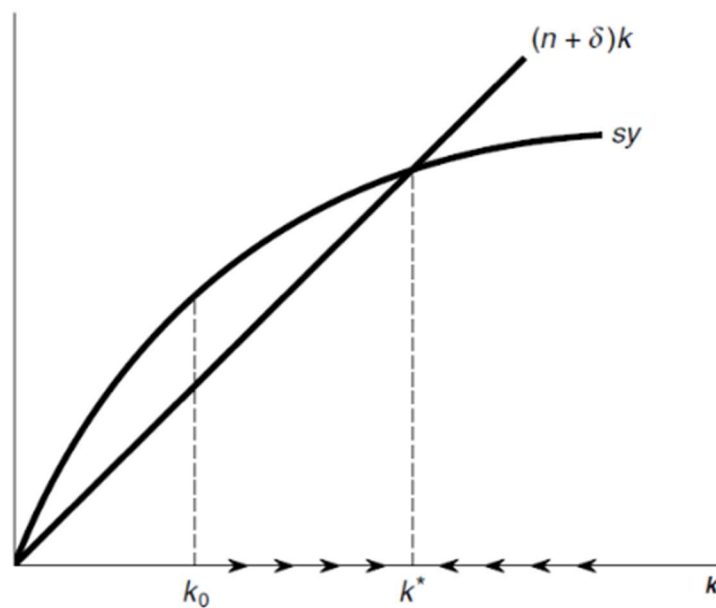
The evolution of capital per worker over time is described by the capital accumulation equation:

$$\dot{k} = sk^{\alpha} - (n + \delta)k$$

Here, s is the savings rate, n is the population growth rate, and δ is the depreciation rate. The first term on the right-hand side represents investment per worker, while the second term reflects capital dilution from depreciation and labour force growth.

The Solow diagram, as seen in Figure 1 illustrates capital accumulating over time through capital deepening until $k = k^*$. This is the point at which investment per worker $sy = sk^\alpha$ exactly equals capital dilution $(n + \delta)k$, causing capital per worker to remain constant so that $\dot{k} = 0$. When $k < k^*$ investment exceeds the amount needed to maintain capital per worker and k rises. When $k > k^*$, investment is insufficient and k declines until the steady state is restored (Jones & Vollrath, 2013).

Figure 1 'The Basic Solow Diagram' (Jones & Vollrath, 2013)



In aging societies, these dynamics become particularly important. A shrinking labour force may initially raise capital per worker (via capital deepening), temporarily increasing productivity. However, aggregate savings often decline as older cohorts dissave, lowering the savings rate s . In the Solow framework, this shifts the investment curve downward, reducing the steady-state level of capital and long-run output per worker. While ageing may raise productivity in the short run, its long-run effects depend critically on saving behaviour and technological progress.

Building on this, Feyrer extends the neoclassical model by incorporating demographic structure into a Cobb-Douglas production function. He finds that countries with a higher share of prime-aged workers (ages 40-49) exhibit higher total factor productivity (TFP), likely due to stronger managerial capacity and innovative potential. As the share of these cohorts declines, a country's innovation capacity and economic efficiency may also weaken (Feyrer, 2007).

Bloom et al. extend this further, modelling productivity as a function of age distribution. Their analysis finds a hump shaped relationship between workforce age and TFP, peaking around age 40. Using quadratic specifications, they estimate that demographic ageing could reduce annual productivity growth by ~0.1 percentage points in OECD countries. They argue that innovation is partially endogenous, driven by education, institutions, and the age composition of innovators, placing their work within the tradition of endogenous growth theory and directly challenging Solow's assumption of exogenous TFP (Bloom, et al., 2016).

Overall, while capital accumulation may mitigate some immediate consequences of ageing, models that overlook the demographic determinants of innovation may fail to capture its full long-term impact on productivity.

2.1.1 Life cycle hypothesis

The Life-Cycle Hypothesis (LCH), originating in Modigliani's neoclassical framework, models how individuals make intertemporal choices over saving, consumption, and labour supply. It assumes agents are perfectly rational and forward-looking, seeking to smooth consumption over their lifetime based on expected income. Individuals typically save during working years and dissave in retirement, implying that population ageing reduces aggregate savings, with implications for capital accumulation and long-run productivity (Modigliani, 1986).

However, these assumptions often break down in reality. The National Research Council highlights that neither individuals nor governments fully anticipate or adjust to the fiscal consequences of ageing, particularly rising pension and healthcare costs. These pressures can crowd out public investment in infrastructure, education, and R&D, ultimately hindering productivity growth. The NRC also notes that ageing alters the workforce's skill mix, and that older workers may struggle to adapt to technological change, especially in dynamic sectors (NRC, 2012). Cognitive studies suggest declines in reasoning and memory with age, potentially limiting adaptability in innovation-driven tasks

Bloom et al. build on the limitations of the life-cycle model by integrating behavioural dynamics with structural drivers of productivity. Rather than treating innovation as exogenous, they model it as partly shaped by demographic trends, human capital, and institutional quality. Their framework connects ageing-related changes in savings and labour

supply to broader effects on innovation systems and fiscal capacity, highlighting how ageing can suppress R&D investment and shift demand away from innovation-intensive sectors (Bloom, et al., 2016).

In contrast to representative-agent models, this integrative perspective shows how ageing affects productivity through both individual and systemic channels. It highlights the importance of policy design, institutional adaptability, and education in mediating the long-run impact of demographic change. While the LCH explains how individuals behave in response to ageing, Bloom et al. offer a more comprehensive view of how those behaviours aggregate into macroeconomic outcomes.

While the Solow model and life-cycle theory offer important insights into how ageing affects capital accumulation and labour supply, both treat technological progress as exogenous. Yet, as Bloom et al. and others argue, innovation is shaped by demographic structure, institutional settings, and policy choices (Bloom, et al., 2016). Understanding ageing's full impact on productivity therefore requires models in which TFP is endogenously determined.

Endogenous growth theory provides this broader structure, linking demographic dynamics to investment in human capital, R&D, and knowledge diffusion (Romer, 1990).

2.1 Empirical Evidence

2.2.1 Core Empirical Evidence: Aging and Productivity Decline

A large body of macroeconomic evidence links population ageing to declining productivity, particularly via reduced labour efficiency and total factor productivity (TFP). Maestas et al. analyse U.S. state-level data from 1980 to 2010 and estimate that a 10% increase in the population aged 60+ results in a 5.5% decline in GDP per capita. Two-thirds of this effect is driven by declining labour productivity, with the remainder due to falling participation rates. To address endogeneity in age structure, the authors implement an instrumental variable strategy using historical fertility rates (Maestas, et al., 2023). However, the use of GDP per capita as the dependent variable limits direct inference about productivity per worker.

Lee and Shin expand this analysis to 35 OECD countries using a growth accounting framework with panel fixed effects. They find that a 10% rise in the old-age dependency ratio reduces GDP per capita growth by 0.18-0.27 percentage points annually, with the effect operating almost entirely through declining TFP. While their controls for education, capital

accumulation, and participation enhance internal validity, causal identification remains incomplete, and results may not generalise beyond advanced economies (Lee & Shin, 2021).

Feyrer focuses more explicitly on TFP by incorporating age structure into a Cobb-Douglas production function. Using cross-country panel data, he finds that a larger share of prime-aged workers (ages 40-49) is strongly associated with higher productivity, while younger and older cohorts correspond to lower TFP. Although the findings are robust, the assumptions of constant returns to scale and fixed elasticities may constrain the model's adaptability across institutional or demographic contexts (Feyrer, 2007).

Collectively, these findings suggest a consistent pattern in which ageing contributes to reduced productivity via changes in workforce composition and weakened innovation dynamics. However, their emphasis on high-income countries and broad national indicators raises questions about applicability in emerging or less-developed economies with differing institutional frameworks.

2.2.2 Nonlinear and Context-Dependent Effects of Aging on Economic Growth and Productivity

While ageing is often associated with declining economic performance, recent studies emphasise that its effects are nonlinear and highly dependent on context.

Lee and Shin analyse 35 OECD countries and identify a threshold beyond which the old-age dependency ratio begins to significantly reduce GDP growth. Below this point, marginal effects are negligible. Their panel fixed effects model controls for unobserved heterogeneity but does not fully address endogeneity concerns (Lee & Shin, 2019). While the study uses GDP growth rather than direct productivity measures, it highlights that the economic effects of ageing vary substantially across demographic contexts.

Yang et al. (2021) apply an extended Mankiw Romer Weil growth model to 186 countries and find an inverted U-shaped relationship between the share of those aged 65+ and GDP per capita. Initial ageing appears to enhance growth through capital deepening and human capital, but this effect reverses beyond a threshold. Using LSDV and TSLS estimation, they show that health investment moderates the negative impact, though it is treated as exogenous.

Institutional factors are not included in the model, limiting insight into how governance or

policy environments may mediate these effects. The findings offer useful insight into how ageing interacts with public investment to shape productivity-relevant growth channels.

Teixeira et al. explore cross-country differences by development level. They find that in developed countries, a 1 percentage point increase in the elderly population share is associated with a 0.24-0.30 percentage point decline in annual GDP growth. In contrast, ageing has no direct effect on growth in emerging or least developed countries (LDCs), where it is the speed of ageing is more influential. Institutional quality is incorporated using Freedom House indices and found significant in developed and emerging countries, though not in LDCs.

Together, these studies show that ageing's effects are conditional on demographic structure and broader institutional environments. The threshold patterns they identify align with the demographic window of opportunity framework, which theorises that the timing and composition of age structure can produce either growth or productivity drags (Crombach & Smits, 2020).

2.2.3 Drivers and Moderators of Aging's Impact on Productivity

Some studies challenge the idea that ageing affects productivity in a uniform way, instead exploring how factors like sectoral composition, innovation intensity, and policy context influence its impact.

Aiyar et al., using panel IV estimation for European countries, find that workforce ageing significantly reduces total factor productivity (TFP), particularly in countries with higher initial productivity. The effect is strongest in innovation-intensive sectors, where ageing appears to hinder knowledge diffusion and adaptability. Their model controls for capital deepening, labour composition, and structural change, reinforcing the view that ageing interacts with sectoral innovation dynamics to influence TFP growth (Aiyar, et al., 2016).

At the micro level, Prskawetz et al. use linked employer-employee data from Austria and Sweden to examine firm-level productivity. They identify a hump-shaped relationship between workforce age and output, with peak productivity among firms employing a greater share of workers aged 30-49. The study highlights that older workers may be less adaptable to changing technologies or work processes, and that firm performance is highly sensitive to

workforce age composition (Prskawetz, et al., 2006). While their analysis is limited to two countries, the use of granular data provides strong internal validity.

Marios et al. adopt a microsimulation approach to estimate long-run productivity outcomes under different policy scenarios in European countries. They show that increasing educational attainment and net migration can offset ageing's negative effects, especially when aligned with supportive policy environments. However, the model's reliance on simulation assumptions limits its predictive certainty, and its effectiveness depends on its institutional responsiveness.

These studies suggest that ageing's impact on productivity is not fixed but conditional, shaped by structural features like sectoral composition, education systems, and innovation capacity. This highlights the need for empirical models that examine interaction effects and account for cross-country variation, particularly when analysing long-term productivity trends

2.3 Research Gap and Contribution

While numerous studies associate ageing with declining productivity or GDP growth, many rely on proxies such as GDP per capita and are largely limited to high-income countries (Maestas et al., 2023) (Feyrer, 2007). This dissertation builds on Lee and Shin's fixed effects model but advances the analysis by using GDP per person employed, a more direct measure of labour productivity, to better capture productivity-specific effects. It extends the data period to 2022, allowing for the inclusion of post-pandemic dynamics absent in earlier research. The model also incorporates lagged variables and interaction terms to explore whether structural factors, such as capital investment, moderate the impact of ageing on productivity.

By incorporating subgroup analysis across development levels, building on Teixeira et al., this study examines whether the effects of ageing differ between advanced and developing economies (Teixeira, et al., 2017). Although it does not analyse on low-income countries due to data limitations, this approach still facilitates exploration of how demographic pressures interact with structural conditions in a broader international context. The study seeks to address key methodological and conceptual gaps in the literature and to enhance

understanding of how ageing influences productivity across diverse demographic and institutional settings.

3 Data

3.1 Overview

This study uses publicly available secondary data sourced entirely from the World Bank. A balanced panel dataset of 37 countries, observed annually from 1997 to 2022, was constructed, resulting in 962 observations. Country selection was based on the availability of key economic and demographic indicators across the entire period. Nations with substantial missing data were excluded to maintain the consistency and reliability of the panel. For smaller gaps, where data were available for both preceding and subsequent years, linear interpolation was applied to ensure a complete dataset with no missing values. 2022 represents the most recent year for which consistent and comparable data across all variables was available, ensuring that the study captures both the immediate impacts of the COVID-19 pandemic and the initial stages of post-pandemic economic adjustment.

The final sample consists of 29 developed and 8 developing economies, classified according to the United Nations' *World Economic Situation and Prospects 2024 report* (United Nations, 2024). To explore potential heterogeneity in the relationship between demographic shifts and productivity, the analysis is conducted the full sample and separately by development group. While the sample is weighted toward developed countries, the inclusion of developing economies enables a preliminary comparison across broader structural and demographic contexts.

3.2 Variables

3.2.1 Dependent Variable

Labour productivity is measured using GDP per person employed, expressed in constant 2021 purchasing power parity (PPP) US dollars. This variable captures the average economic output produced by each employed individual, offering a direct measure of worker efficiency that adjusts for price level differences across countries and over time.

GDP per person employed is particularly well-suited for analysing demographic change because it isolates labour productivity from fluctuations in population age structure. Although

GDP per capita is commonly used, it reflects output per individual regardless of labour force status and can be skewed by changes in the share of non-working-age populations. This makes GDP per person employed a more accurate measure of actual worker productivity. The distinction is important, as much of the existing literature uses GDP per capita as a proxy, which can blur the real effects of ageing on output (Maestas, et al.,2023) (Yang, et al., 2021). By focusing on the employed population, this study adopts a more precise metric for evaluating how ageing influences productivity through changes in labour force composition and efficiency.

3.2.2 Independent Variable

The aging population is the independent variable in this analysis and is measured as the percentage of the population aged 65 and over. This is consistent with the OECD definition, which defines the elderly population as individuals aged 65+ (OECD, 2019). This provides a straightforward and comparable indicator of demographic aging, making it appropriate for panel analysis. The same measure is also used in previous empirical studies examining the economic effects of aging (Bloom et al., 2016) (Yang, et al.,2021).

3.2.3 Control Variables

To account for structural and policy-related influences on productivity, the model includes a set of theoretically grounded control variables.

Fertility rate is used to capture demographic trends that shape the future labour supply and is measured as the total number of births per woman. Declining fertility accelerates population ageing, increasing dependency ratios over time and reinforcing downward pressures on productivity as emphasised in previous research (Lee & Shin, 2019).

Life expectancy at birth (total, years) serves as a proxy for human capital and general health outcomes which influence workforce productivity and are commonly used in modelling in this topic area (Bloom et al., 2016). Countries with higher life expectancy often benefit from stronger education systems, better health infrastructure, and greater investment in human capital, which can help mitigate some of the negative effects of an ageing population.

R&D expenditure as a share of GDP is included to reflect technological innovation capacity, a key moderating factor in endogenous growth frameworks. Aiyar et al. emphasise that

innovation can offset productivity slowdowns associated with population ageing (Aiyar, et al., 2016). However, R&D's effects may be subject to lags and uneven distribution across sectors, potentially limiting its short-run explanatory power.

Government effectiveness is included to capture institutional quality. The world bank measures this on a standard normal scale from -2.5 to 2.5, with higher values indicating stronger governance. Effective institutions can support adaptive responses to demographic ageing by facilitating investment in skills, innovation, and labour market reforms. However, because the measure is constructed from aggregated expert assessments and survey-based perceptions, it may not fully capture the functional capacity or enforcement quality of institutions (Kaufmann, et al., 2010).

Gross capital formation (% of GDP) is included to capture investment in physical capital, which complements labour and supports productivity growth. As noted in Prskawetz et al. analysis, capital deepening can help sustain output as the workforce ages (Prskawetz et al., 2006). However, the volume of investment does not necessarily reflect its quality or efficiency, which may limit its effectiveness in offsetting ageing-related productivity pressures.

Finally, the **labour force participation rate** (ages 15+) is included to capture the active share of the working-age population. A declining participation rate reduces the size of the productive workforce, thereby intensifying the economic challenges associated with population ageing. However, participation is also shaped by informal employment, gender norms, and institutional factors, which vary across countries and may not be fully captured in the data (Clark & Summers, 1982). Including labour force participation as a control variable is consistent with Lee and Shin's framework (Lee & Shin, 2021).

3.3 Hypothesis

Based on existing theoretical and empirical literature, it is anticipated that a higher proportion of the elderly population will be associated with lower labour productivity. However, the strength of this relationship is likely to differ based on a country's level of economic development and structural factors such as innovation capacity, governance quality, and investment dynamics. In line with the study's research objectives, the following hypotheses are proposed:

Main Hypothesis

- **H₀:** There is no significant relationship between the share of the population aged 65 and over and labour productivity.
- **H₁:** There is a significant relationship between the share of the population aged 65 and over and labour productivity

Sub-Hypothesis

- **H₀:** The impact of demographic aging on labour productivity does not differ significantly between developed and developing economies.
- **H₁:** The impact of demographic aging on labour productivity differs significantly between developed and developing economies.

This set of questions and hypotheses provides the foundation for the empirical strategy that follows. The next section outlines the methodology used to evaluate these relationships, detailing the panel structure, model specifications, and econometric techniques applied to test the core assumptions.

4. Methodology

4.1 Initial Diagnostic Tests

Before commencing the main econometric analysis, a series of diagnostic steps were undertaken to ensure the reliability and appropriateness of the data for panel modelling.

A Levin-Lin-Chu panel unit root test was performed on each variable to ensure stationarity and avoid spurious regression. Stationarity is a key assumption in regression analysis, as non-stationary variables can produce misleading results. The test rejected the null hypothesis of non-stationarity for all variables at the 5% significance level ($p < 0.05$), confirming that the data were stationary in levels. As a result, detrending the data (e.g. first differencing) was not required.

Histograms were used to assess the distribution of each variable, revealing significant right-skewness in GDP per person employed and R&D expenditure. To improve normality, both variables were log-transformed following the approach of Maestas et al. (Maestas, et al., 2023). However, even after transformation, histograms showed that two countries remained

extreme outliers in the log of GDP per person employed. These were removed from the dataset to improve distributional symmetry and enhance the reliability of the variables used in subsequent modelling.

Figure 2 presents the summary statistics for the transformed variables used in the final specification, based on the cleaned dataset. These statistics provide an overview of the distribution and variability of the key indicators used in the final model.

Figure 2 Summary statistics

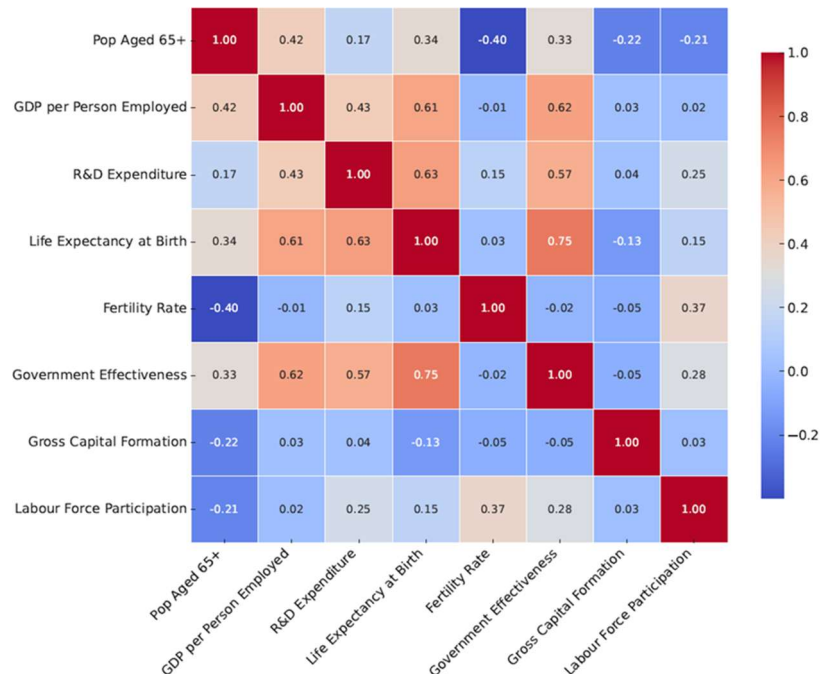
		Summary Statistics			
Variable Notation	Description	Mean	Standard Deviation	Minimum	Maximum
<i>LnProd</i>	Log of GDP per person employed (productivity)	11.29	0.45	9.21	12.44
<i>Age</i>	Percentage of population aged 65 and over	15.05	4.26	4.66	23.92
<i>LnRD</i>	Log of R&D expenditure (% of GDP)	0.19	0.25	-2.15	1.80
<i>GCF</i>	Gross capital formation (% of GDP)	23.71	4.83	8.93	53.71
<i>LifeE</i>	Life Expectancy (at birth, total years)	77.41	4.38	63.31	84.56
<i>FertR</i>	Fertility Rate (total number of births per woman)	1.64	0.40	0.78	3.32
<i>GovE</i>	Government Effectiveness Estimate (-2.5 to 2.5)	0.94	0.78	-1.07	2.35
<i>LFP</i>	Labour Force Participation Rate (ages 15+)	59.88	5.82	46.23	77.76

While gross capital formation exhibited considerable variation across the sample, the histograms showed no signs of extreme skew or outliers. Combined with the filtering of two distortionary countries, this reinforces confidence in the underlying data quality.

A correlation matrix of all variables in their original form was then produced to check for potential multicollinearity. There were some strong associations particularly between life

expectancy and government effectiveness. These initial results should be interpreted with caution, as correlation alone does not imply a causal relationship (Freedman, 1997).

Figure 3 Variable correlation matrix



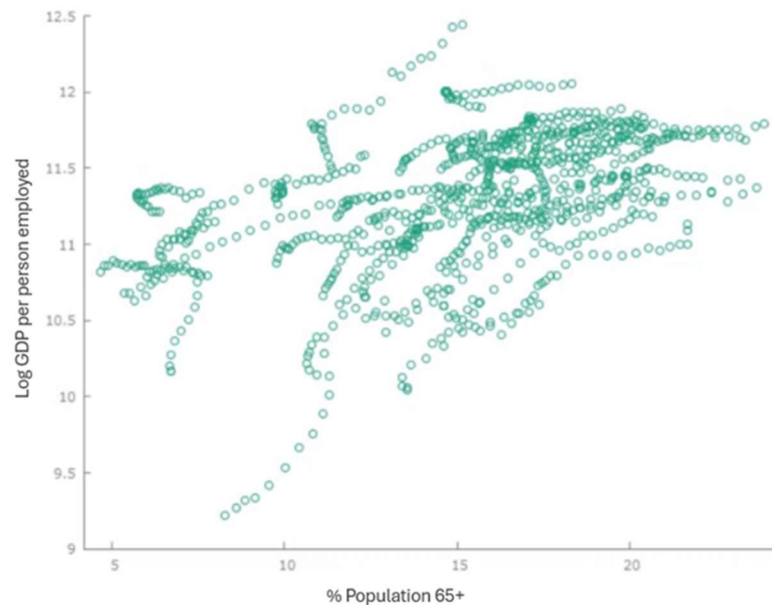
Finally, to further investigate multicollinearity, Variance Inflation Factors were calculated. All VIF values were below the conventional threshold of 10, with none exceeding 3, indicating that multicollinearity was not a significant concern.

4.2 Exploratory Analysis and Baseline Estimation

After the initial diagnostic tests, a pooled OLS regression was conducted to estimate the baseline relationship between the proportion of the population aged 65 and over and labour productivity, using the log-transformed productivity measure. The results showed a statistically significant but unexpectedly positive coefficient, suggesting that increases in the elderly population were associated with small improvements in productivity. This was inconsistent with most theoretical and empirical literature.

To assess the nature of the relationship between ageing and productivity, a scatter plot of the log of GDP per person employed against the percentage of the population aged 65 and over was created (Figure 4).

Figure 4 Scatter Plot of Dependent and Independent Variables



The plot suggests a generally positive association, but the wide dispersion of values and absence of a clearly defined turning point indicate that the relationship may not be strictly linear. To investigate this possibility more rigorously, a quadratic term for the ageing variable was added to the pooled OLS model, denoted as '*SqAge*'. This allowed for a formal test of whether the relationship between ageing and productivity followed a non-linear pattern.

When the linear and squared ageing terms were included together in the pooled OLS model, both coefficients were statistically insignificant, with the squared term positive. This outcome is inconsistent with theoretical expectations and suggests model misspecification, reinforcing the limitations of relying on pooled OLS alone to estimate the ageing-productivity relationship (Woolridge, 2016).

4.3 Panel Data Estimation: Fixed vs Random Effects

To overcome the limitations of pooled OLS and account for unobserved heterogeneity, both fixed and random effects panel models were estimated. These approaches control for country-specific characteristics that do not vary over time, as well as time-specific shocks common across countries. This was particularly important for isolating the effect of ageing on

productivity from broader structural or macroeconomic influences. Under both specifications, the squared ageing term became negative and statistically significant. This result aligns with theoretical expectations and previous empirical findings (Yang et al., 2021), and marks a notable shift from the pooled OLS results. The contrast highlights the importance of using panel data methods to more accurately model complex demographic-economic relationships.

To decide between the fixed and random effects models, a Hausman test was conducted. The test produced a p-value of 0.043, which is just below the 5% significance threshold. This provided sufficient evidence to reject the null hypothesis that the random effects estimator is consistent, indicating likely correlation between the unobserved country-specific effects and the explanatory variables. As a result, the fixed effects model was selected for the main analysis, an approach also supported in the literature (Lee & Shin, 2021).

While the baseline fixed effects model offers useful insights, it assumes immediate effects of demographic and innovation-related variables. However, both theory and empirical research suggest that changes in population ageing, or R&D investment may influence productivity with a time lag, as their effects unfold gradually. For example, Bloom et al. highlight that demographic change affects productivity through long-term shifts in human capital, innovation capacity, and institutional adaptation- processes that evolve over time rather than instantaneously (Bloom et al., 2016). To account for these dynamics, the model was extended to include lagged explanatory variables, capturing the delayed impact of demographic and innovation-related factors on productivity.

To assess potential endogeneity, a Durbin-Wu-Hausman test was also applied. However, the test proved inconclusive, as the generated residual was perfectly collinear with existing regressors. Although the original Hausman test supported the use of fixed effects, the possibility of endogeneity, particularly reverse causality between productivity and demographic structure, remains a valid concern. This issue is addressed further in the limitations section.

Taken together, the statistical evidence and strong theoretical justification for a correlation between regressors and unobserved country-specific effects support the use of the fixed effects model as the preferred specification.

4.4 Final Model Specification

The final model specification builds on previous versions by incorporating both delayed and non-linear effects. Lagged R&D and ageing variables capture the gradual influence of innovation diffusion and demographic shifts, both of which are unlikely to affect productivity immediately. A three-year lag was selected to reflect these delayed effects, while retaining sufficient sample size and avoiding overfitting.

Each modification was tested separately to ensure model stability and interpretability. After confirming that the inclusion of lagged and squared terms was both theoretically grounded and statistically robust, these components were retained in the final fixed effects specification. The final model captures potential delayed and non-linear effects while controlling for unobserved country specific effects that could bias the estimated relationships.

Formally, the preferred specification is defined as follows

$$\begin{aligned} \mathbf{LnProd}_{it} = & \beta_0 + \beta_1 \mathbf{Age}_{it-3} + \beta_2 \mathbf{SqAge}_{it-3} + \beta_3 \mathbf{LnRD}_{it-3} + \beta_4 \mathbf{GCF}_{it} + \\ & \beta_5 \mathbf{LifeE}_{it} + \beta_6 \mathbf{FertR}_{it} + \beta_7 \mathbf{GovE}_{it} + \beta_8 \mathbf{LFP}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \end{aligned}$$

This equation reflects the final empirical model taken forward for analysis. It forms the foundation for the subsequent subgroup exploration by development level and enables a rigorous assessment of the central research question.

5. Results

5.1 Core Results

Building on the model specification outlined previously, the final fixed effects model was estimated for three samples: the full panel, developed economies, and developing economies.

Figure 5 – Fixed Effects Results¹

Variable	Full Sample	Country Economic Development split	
		Developed Economies	Developing economies
<i>Age</i> ($t-3$)	0.128 *** (0.038)	0.136 *** (0.037)	0.099 (0.059)
<i>SqAge</i> ($t-3$)	-0.003 ** (0.001)	-0.003 ** (0.001)	-0.001 (0.002)
<i>LnRD</i> ($t-3$)	0.012 (0.042)	-0.38 (0.044)	0.210 (0.132)
<i>LifeE</i>	0.027 *** (0.007)	0.020 ** (0.008)	0.047 ** (0.014)
<i>FertR</i>	0.313 *** (0.076)	0.237 *** (0.075)	0.533 ** (0.197)
<i>GovE</i>	0.106 ** (0.049)	0.142 ** (0.057)	-0.102 (0.069)
<i>GCF</i>	0.007 *** (0.002)	0.006 *** (0.002)	0.007 (0.004)
<i>LFP</i>	-0.002 (0.005)	0.003 (0.005)	-0.032 * (0.016)
Constant	7.205 *** (0.464)	7.520 *** (0.654)	7.297 *** (0.877)
Statistical Tests			
Observations	962	754	208
P value (F)	3.26e-13 ***	3.53e-9 ***	8.54e-51 ***
R^2	0.68	0.71	0.72
Wald Test (Heteroskedasticity)	P = 0.000	p = 0.000	p = 0.000
Woolridge Test (Autocorrelation)	P = 0.000	p = 0.000	p = 0.000

¹ Significance levels are * p<0.1, ** p<0.05, *** p<0.01.

Standard errors are written in parenthesis

5.1.1 Ageing Population

Across all three samples, the relationship between ageing and labour productivity exhibits a non-linear form, consistent with findings in parts of the existing literature. In both the full and developed economy models, the coefficient on the share of the population aged 65 and over is positive and statistically significant at the 1% level, while the squared term is negative and significant at the 5% level (-0.003 in both cases). This confirms an inverted U-shaped relationship. Moderate ageing may enhance productivity via accumulated experience and human capital, but beyond a certain threshold, these gains diminish as dependency burdens and age-related costs rise. These findings are consistent with prior empirical and theoretical work on ageing in high-income, capital-rich societies (Yang et al., 2021).

In developing countries, both ageing coefficients have the expected signs but are not statistically significant. This means there is no reliable evidence of either a positive marginal effect or a non-linear turning point. This may reflect an earlier stage of demographic transition, in which ageing has not yet exerted strong economic effects. Structural factors such as weaker institutions, data limitations, or greater macroeconomic volatility may be obscuring underlying demographic–productivity dynamics.

These results support the study’s main hypothesis, providing evidence of a significant relationship between the share of the population aged 65 and over and labour productivity, particularly in more advanced economies. The findings highlight the importance of modelling non-linear demographic effects. The R-squared values, 0.68 for the full sample, 0.71 for developed countries, and 0.72 for developing countries, indicate strong overall explanatory power, especially with the inclusion of structural controls and fixed effects.

5.1.2 Control Variables

Life expectancy was positively and significantly associated with productivity across all samples. This aligns with the expectation that healthier populations contribute more effectively to economic output. The effect was particularly strong in developing economies, where gains in health may translate into larger relative improvements in human capital.

Fertility rate also exhibited a consistently positive and highly significant association with productivity. While this may initially seem counterintuitive, especially given short-term

dependency costs, it may reflect expectations of future labour force growth or broader demographic trends not fully captured by ageing measures alone.

Government effectiveness was significant and positive in the full sample and developed economies but insignificant, and slightly negative, in developing countries. This suggests that governance contributes more reliably to productivity where institutional capacity is stronger. In weaker institutional environments, improvements in governance may not yet be sufficient to enhance economic performance.

R&D expenditure was not statistically significant in any sample, though the coefficient was largest in developing countries. This may reflect higher potential returns to innovation in less advanced economies, even if not yet realised in productivity gains. The small negative coefficient in developed economies is consistent with diminishing returns to R&D near the technological frontier (Jones, 1995).

Gross capital formation was significantly associated with productivity in both the full and developed economy samples, but not in the developing country group. This pattern may reflect more efficient capital deployment and stronger institutional quality in advanced economies, consistent with the finding that capital investment contributes more to growth when supported by effective institutions (Barro, 1991). In lower-income contexts, weaker governance and limited absorptive capacity may reduce the productivity-enhancing effects of investment.

Labour force participation was insignificant in all models. This may be due to multicollinearity with other demographic variables, or because participation rates alone do not reflect productivity-related factors like worker skill, hours worked, or employment type. More granular labour market indicators would be needed to explore this further.

5.1.3 Cross-Sample Comparison

As mentioned previously, developed economies show a statistically significant inverted U-shaped relationship between ageing and productivity, consistent with demographic theory in high-income, capital-rich contexts. In contrast, no statistically significant relationship is found in developing countries. Rather than implying the absence of any underlying effect, this likely reflects a combination of earlier demographic transitions, limited institutional

capacity, and greater macroeconomic volatility that make it more difficult to detect stable patterns.

These results suggest that the economic impact of ageing is not uniform across countries but depends on structural readiness. Advanced economies may be better equipped to realise the benefits of moderate ageing, such as accumulated experience and innovation spillovers, before hitting demographic thresholds that reduce productivity. In contrast, developing countries may lack the institutions, infrastructure, or capital intensity needed to translate demographic change into productivity outcomes.

Differences in the behaviour of control variables reinforce this interpretation. Governance and health are significant only in developed economies, while R&D and capital investment play a comparatively larger role in developing ones, though further interaction testing would be required to confirm this formally.

Overall, these findings support the second sub-hypothesis and highlight the importance of context-sensitive analysis. As countries progress through demographic transitions, their ability to harness or mitigate the effects of ageing will depend not only on population structure but also on the broader institutional and economic environment. This reinforces the need for policy responses that are tailored to each country's demographic and institutional context.

5.2 Robustness Tests

5.2.1 Testing the Independent variable

The old-age dependency ratio was tested as the independent variable as opposed to percentage of the population aged 65 and over, to assess the robustness of the findings. This variable captures the ratio of older dependents to the working-age population and is commonly used as a proxy for demographic ageing. When re-estimating the models with this specification, the inverted U-shaped relationship between ageing and productivity persisted, reinforcing the earlier evidence of a non-linear dynamic. Notably, R&D expenditure, previously insignificant, became statistically significant in the full sample, suggesting that the innovation–productivity link may be more sensitive to the way ageing is measured.

5.2.2 Time dummies

To account for global shocks and time-specific factors that may influence productivity across all countries, such as financial crises or the pandemic, year dummies were added to the fixed effects model. These time fixed effects capture unobserved heterogeneity that varies across time but is constant across countries, ensuring a more robust identification of the ageing–productivity relationship.

In both the full sample and the developed country subsample, the inclusion of time dummies preserved the main findings. The linear term for the share of the population aged 65 and over remained positive and significant, while the squared term was negative and significant, confirming inverted U-shaped relationship found previously. The signs, magnitude, and statistical significance of the ageing terms showed little sensitivity to the inclusion of year dummies, suggesting that the demographic-productivity link is stable and not driven by unobserved time-varying shocks.

In contrast, the developing economy subsample exhibited greater volatility. A larger number of year dummies were statistically significant, reflecting more pronounced time-specific shocks or shifts in productivity unrelated to demographics. At the same time, both ageing coefficients lost statistical significance, indicating that in these countries, the link between ageing and productivity is weaker, less stable, or more sensitive to omitted variables. These findings suggest structural factors and macroeconomic conditions may overshadow demographic effects in developing economies.

5.2.3 Interaction Term

As a further robustness check, an interaction term between the ageing population and gross capital formation was included to test whether the impact of ageing on productivity depends on investment levels. This draws on neoclassical growth theory, which identifies capital accumulation as a key driver of productivity (Solow, 1956). In ageing economies, higher investment in physical capital may help offset the effects of a shrinking workforce by enhancing labour efficiency and supporting capital deepening (Lee & Mason, 2010). A high-investment environment could therefore mitigate age-related productivity pressures, making outcomes contingent on a country's investment capacity.

Across all samples the interaction term was negative, in line with theoretical expectations, but statistically insignificant. In the developing country subsample, the coefficient was -0.003 and was closest to significance yet still fell short of conventional thresholds. These results suggest no systematic moderating effect of investment on the ageing–productivity relationship within the scope of this model. The inclusion of the interaction also marginally reduced R^2 values across all specifications, indicating a slight decline in explanatory power.

Several factors may explain the lack of significance. The relationship may be non-linear or contingent on other factors such as institutional quality or human capital. The use of gross capital formation as a share of GDP may also be too broad to capture variation in investment quality or sectoral allocation. Effects may take longer to materialise, as capital often influences productivity with a delay. Future research could explore longer lags, disaggregated interactions, or threshold effects using non-linear models.

Given these limitations, the interaction model was not carried forward as the preferred specification. However, it highlights a potential mechanism worthy of further investigation using richer or more granular data.

5.2.4 Diagnostic Checks

Finally, diagnostic checks were performed to assess the validity of model assumptions. The Wald test strongly rejected the null of homoskedasticity across all three samples ($p < 0.001$), indicating its presence. The groupwise Wald test is widely used in panel data but assumes constant variance within each country and may be less reliable in small samples (Greene, 2012).

The Wooldridge test also rejected the null of no first-order autocorrelation ($p < 0.001$), indicating that the model errors related to productivity are serially correlated, which implies persistence of unobserved shocks over time.

These tests were applied to models already estimated using robust standard errors clustered at the country level, which adjust for both heteroskedasticity and serial correlation in the estimation of standard errors. Although these issues remain in the residuals, the use of robust inference ensures valid significance testing. Together, these diagnostics support the reliability of the model's inference across samples and specifications.

5.3 Limitations and Future analysis

The fixed effects model does not fully address the issue of endogeneity. The relationship between ageing and productivity may be bidirectional. This study focuses on how demographic ageing influences productivity; however, it is also plausible that productivity growth contributes to ageing by raising income, improving healthcare access, and increasing life expectancy. This potential reverse causality would bias the estimated effects of ageing if not adequately addressed, and it highlights the need for caution when interpreting coefficients as causal. Unobserved time-varying factors, such as pension reforms, institutional shifts, or changes in health systems may also influence both ageing and productivity, leading to omitted variable bias.

An attempt to test for endogeneity, using the Durbin-Wu-Hausman test, was inconclusive, as the residual was perfectly collinear with existing regressors. This reflects a mechanical limitation of the test rather than a flaw in the model specification. Given the risk of endogeneity, future work should explore instrumental variable approaches, such as two-stage least squares (2SLS), or consider dynamic panel methods to better isolate causal effects. Historical fertility rates, for example, may serve as a suitable instrument for ageing by capturing long-run demographic shifts without directly influencing current productivity.

Although regressions were already estimated using robust standard errors, diagnostic tests still detected heteroskedasticity and autocorrelation. This suggests that the residual variance is not fully addressed and that more advanced estimators may be considered in future analysis.

There are also limitations in the dataset itself. The split between developed and developing economies was unbalanced due to more complete data availability in high-income countries, which may affect the generalisability of results.

Key variables such as education or human capital indicators were considered but excluded due to significant data gaps over the panel period. In addition, proxy variables such as gross capital formation may be too broad to capture the quality or sectoral relevance of investment.

While the model incorporates a three-year lag to capture delayed effects of ageing and innovation, this lag structure may not fully reflect the longer-term nature of demographic

transitions or R&D processes. Future studies could test longer lag lengths to explore the persistence and timing of these effects more precisely.

6. Conclusion and Policy Implications

This study demonstrates that the relationship between ageing and productivity is neither uniform nor linear, but highly dependent on a country's structural and institutional context. In developed economies, where demographic transitions are further advanced, an inverted U-shaped relationship emerges. Moderate ageing appears to enhance productivity, likely through experience retention and labour quality, but this benefit diminishes once dependency burdens rise. In developing economies, the effects of ageing are weaker and statistically uncertain, highlighting that demographic change does not automatically translate into economic outcomes.

Rather than suggesting a universal trajectory, these findings reinforce that the economic consequences of ageing are shaped by health systems, governance, human capital, and the ability to mobilise investment effectively. The absence of a significant interaction between capital formation and ageing highlights that the volume of investment is not enough. The importance lies in the institutional readiness and targeted allocation.

These insights emphasise that the economic consequences of ageing are shaped less by demographic trends themselves and more by a country's institutional strength and policy readiness. It can support long-run productivity and economic stability, but only in economies equipped with the governance, investment capacity, and policy tools to manage demographic change effectively. The differences in how ageing affects productivity across countries show that a single policy approach will not work for all. Instead, strategies must be tailored to each country's stage of demographic transition and its ability to support ageing populations through institutions, health systems, and economic resources.

While population ageing can support productivity gains, these benefits are bounded beyond a certain threshold and further ageing may impose economic constraints unless mitigated by structural adaptation. Beyond this demographic threshold, continued increases in the elderly population may begin to constrain economic performance. This creates a narrow productivity window a period during which ageing still contributes positively to growth, but after which its effects may reverse unless offset by structural reforms.

The global population aged 65 and over is predicted to have more than doubled by 2050, reaching 1.6 billion (United Nations, 2022). This trend suggests that many countries are approaching, or have already passed, the peak of productivity gains from ageing. Effective and forward-looking policy interventions will be critical to navigating this demographic shift.

In developed economies, where demographic transitions are more advanced, the results suggest that productivity benefits from ageing are already flattening. Policy should focus not only on extending working lives, but on enhancing the quality of older workers' participation. This includes flexible retirement, age-responsive workplace design, and continuous skill development. Gabriele et al. find increases in retirement age can reduce average productivity if not supported by adequate investments in health and training (Gabriele et al. 2018).

In developing economies, where ageing remains at an earlier stage, the analysis does not find statistically significant effects. However, these countries may still be situated within the demographic window of opportunity which is characterised by a high share of working-age individuals relative to dependents. Whether this advantage can be translated into productivity gains depends on the strength of institutions, public health, and education systems. The relevance of life expectancy and governance in this study highlights the need for broader structural investment. As Crombach and Smits argue, capitalising on the demographic window requires more than favourable age structures; it depends on sound policy and strong institutional foundations (Crombach & Smits, 2020).

The insignificance of the capital $\times$ ageing interaction in the analysis suggests that investment quantity alone is not enough. What matters is how and where capital is allocated, particularly toward innovation, skill development, and institutional reform. In lower-income settings, where absorptive capacity is weaker, this becomes even more critical. This suggests that capital investment must be complemented by institutional readiness and effective allocation to deliver productivity gains in ageing contexts.

As population ageing accelerates globally, sustaining productivity will depend on investments in human capital, innovation systems, and institutional strength. Ageing is not inherently a drag on productivity, but its impact is contingent on how governments respond. Those that act early and strategically can turn demographic change into a platform for resilience and growth. Those that delay risk reduced growth potential, shrinking workforces, and long-run economic weakness.

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