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The implications of population ageing on economic growth: Evidence of nonlinearity

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ABSTRACT

The purpose of this study is to investigate the influence of population ageing on economic growth, a topic that has received inconclusive results. The Fixed Effects Model is used to analyze 5-year non-overlapping growth regressions on a panel of 72 nations spanning three decades. Data is extracted from the World Bank database and Penn World Tables. Findings indicate that in the short-run, population ageing positively impacts economic growth; nevertheless, a nonlinear relationship is observed in the long-run, highlighting the existence of a threshold. The findings remain robust upon proxying the old-age dependency ratio for the share of the elderly. The study identifies the threshold below (above) at which ageing populations impact economic growth positively (negatively). Marginal Effects support our findings, establishing that the detrimental effect on growth intensifies as ageing deepens. The research also identifies a notable nonlinear relationship between economic growth and population ageing in developed economies. Policy implications such as promoting healthy ageing, longer working years, encouraging savings, enhancing productivity via capital investments, and contributions of experienced older workers to the knowledge economy will facilitate reaping the silver demographic dividend and will help nations cope with and minimize the adverse impact of population ageing on economic growth.

Contribution/ Originality: This study pioneers the impact of population ageing on economic growth by presenting an in-depth analysis of the nonlinear relationship, comparing nations at different stages of their ageing transition, and identifying the threshold level below (above) which ageing populations promote (adversely affect) economic growth.

1. INTRODUCTION

Population ageing encapsulates an upsurge in the percentage of individuals aged 65 years and older within the overall population. The United Nations (UN) has projected that the global share of the elderly will rise by four times from 595 million to 2 billion between the years 2000 and 2050 (UN, 2022). In 2018, the global share of older adults surpassed that of children under five years old, marking an unprecedented and unparalleled historical milestone. This phenomenon is predicted to accelerate as the twenty-first century advances.

Population ageing ranks as a prominent concern on the economic and policy agendas of several nations and global bodies. This is understandable because an ageing populace, in the opinion of Bogetic et al. (2015), presents economic, budgetary, health, and social transformations that nations are expected to face in the ensuing years. At the micro level, poverty and insecurity among older adults are realities, with inadequate resources and income within the family

becoming evident as the age structure transforms. Kastor and Mohanty (2018) demonstrate that, as opposed to non-elderly families, those with older members are more inclined to experience higher out-of-pocket costs and, thus, higher household expenditure. Mishra and Rajan (2017) contend that the presence of an older person in the household very often breaks down the existing resource-sharing mechanism, reducing individual welfare.

Researchers also intensely study the macroeconomic implications. The rapid ageing of humanity has a tremendous influence on public social security, pensions, and insurance mechanisms (Tang & Li, 2021). It also affects national savings. Pascual-Saez, Cantarero-Prieto, and Pires-Manso (2020) contend that because older individuals consume less than working-age people, aggregate consumption falls, leading to declining aggregate demand. Broniatowska (2019) posits that ageing populations further exercise a downward-pull on inflation if declining aggregate demand cannot be matched entirely by reduced supply.

Ferrero, Gross, and Neri (2019) underscore the impact on monetary policy: as declining inflation typically results in lower nominal interest rates, the deflationary forces triggered by changing demographics indicate a higher possibility that monetary policy's ability to stabilize nominal interest rates will constrain it in the medium to long term. Another major area impacted by population ageing is the health sector. With the epidemiological transition accompanying population ageing in the form of new generational diseases, Reid et al. (2022) bring to the fore the enormous pressure governments face to drastically restructure the public health system, which is costly and time-consuming. The ageing of the age pyramid also greatly impacts labor force participation and efficiency. Dallmeyer, Wicker, and Breuer (2017) portray how efficiency and productivity are negatively impacted by a rise in senior workers, resulting in negative repercussions on growth. Nevertheless, the various mechanisms mentioned above ultimately impact economic growth and stability. Some believe the future is grim and will result in an earthquake (Wallace, 1999) or a silver tsunami (Fox, 2001). Others are optimistic that legislative adjustments may have unfavorable effects.

To best understand the overall impact that population ageing is exerting on the macroeconomy, this paper analyses its implications for economic growth, given that the pace of growth in real Gross Domestic Product (GDP) serves as an important indicator for assessing overall economic health (Callen, 2022). The linkage underlying population ageing and economic growth has received extensive investigation, as outlined in the literature review section. However, the mixed findings concerning the impact—in some cases, negative, in others positive, while in a few others, a nonlinear relationship—leave it a contentious issue. Our study presents an advancement over prior research, as firstly, it seeks to analyze this impact across a panel comprising nations at different stages of their ageing transition, employing 5-year non-overlapping growth regressions. Second, it compares the impact across developed and developing economies. Thirdly, it examines whether this impact intensifies as population ageing deepens, thereby identifying the threshold level for experiencing the adverse impact. Based on the findings of a very significant long-run non-monotonic relation between population ageing and economic growth that intensifies with the deepening of population ageing, especially witnessed among developed economies that are at the advanced stages of the ageing transition, the study offers practical policy implications that policymakers can adopt to cope with, minimise the adverse impact, and thus reap the silver demographic dividend.

2. LITERATURE REVIEW

Much research shows that the implications of ageing populations on economic growth are negative. A few of these examine the impact exclusively on a specific country. In this vein, Ismail, Abd Rahman, Tengku Abdul Hamid, and Said (2016) identify adverse growth repercussions due to an ageing populace from 1980 to 2011 in Malaysia by applying the Autoregressive Distributed Lag (ARDL) technique. Uddin, Alam, and Gow (2016) confirmed a significant negative impact on per capita GDP in Australia due to a rising dependency ratio, using the Dynamic Ordinary Least Squares (DOLS) from 1971 to 2014. Granger causality tests revealed a one-way, short-run causal relationship between the dependency ratio and GDP per capita. Similarly, employing the ARDL approach, Miri,

Maddah, and Raghfar (2019) purported that a rising population aged 64 and older reduces the marginal saving inclination, consequently challenging the process of capital accumulation and harming the Iranian economy from 1987 to 2017.

Several studies examining a set of regions also trace a negative growth impact. For instance, while estimating the effects of population ageing among a panel of 12 emerging Asian economies between 2011–2020 and 2021–2030, Park, Lee, and Mason (2012) report considerable negative growth repercussions across nations with a significantly greater older population. Bloom, Canning, and Fink (2010) also found proof of sluggish economic growth among countries comprising the Organization for Economic Cooperation and Development (OECD), bearing similarities to the findings of Lindh and Malmberg (2009) among a panel of 15 nations belonging to the European Union (EU). Maestas, Mullen, and Powell (2023) found that throughout the United States of America (USA) from 1980 to 2010, when the proportion of individuals aged 60 years and over rose by 10%, it slowed per capita GDP growth by 5.5%, analogous to the results of Wongboonsin and Phiromswad (2017) from a sample of 122 nations spanning 1960 to 2010. Eggertsson, Lancastre, and Summers (2019), using a two generation Overlapping Generations (OLG) Model, demonstrated that the association between GDP growth rate and ageing has progressively become negative in recent years (2008-2015) by contrasting it with 1990-2008. Conversely, Hyun-Hoon, Kwanho, and Donghyun (2017), adopting a panel of 142 nations from 1960 to 2014, discovered that population ageing exerts a detrimental immediate and long-term growth effect.

Using panel regression models for the period 1970–2010 for 23 EU countries, Cuaresma, Loichinger, and Vincelette (2016) discovered that the influence of ageing on income dynamics varies among nations, with the adverse consequences of ageing societies being more pronounced in comparatively less affluent nations. Basso and Jimeno (2021), employing the general equilibrium model, explored the primary transmission mechanisms through which demographic factors and technological advancements impact economic growth. Their study revealed that, as a consequence of the trade-off between automation and innovation, decreased fertility rates and population ageing result in declines in the expansion of per capita GDP and the share of labor income. Similarly, employing time series analysis with Ordinary Least Squares (OLS), Huang, Lin, and Lee (2019) identified the detrimental effects of a rising old-age dependency ratio on Taiwan's GDP growth rate from 1981 to 2017.

In contrast, many investigations have discovered that ageing has a favorable positive economic growth influence. For instance, Mamun, Rahman, and Khanam (2020) found via time-series modelling that the ageing population of Bangladesh contributed positively to long-run economic prosperity from 1972 to 2015. This could happen since increased capital accumulation raises the output of the working-age populace, thus supplanting the aged population's declining economic engagement. Several studies in China also demonstrated a positive impact. For example, using dynamic regression analysis for 2000-2016, Zhao, He, and Yang (2018) revealed that population ageing exerted a positive growth effect. Similarly, Ruidong (2018) and Li and Zhang (2015) exhibited that the old dependence ratio bears a long-term beneficial influence on China's GDP. This is anticipated to result from a significantly faster per capita GDP expansion compared to that of the older population. Furthermore, Bawazir, Aslam, and Osman (2020) used fixed linear panel data models to analyze data from 10 Middle Eastern countries from 1996 to 2016. Their findings revealed that while the old-age dependency ratio positively impacted growth, the young dependency ratio exerted a negative effect. This led them to conclude that older individuals do not currently constitute a substantial demographic force in the majority of Middle Eastern countries. Similarly, using a partial adjustment framework in a sample of 80 nations, Hyun-Hoon Lee, Huh, Lee, and Lim (2013) demonstrated that over the period 1960-2005, an ageing populace did not hinder economic growth, akin to the results of Pham and Vo (2021), who employed quantile regression for a panel of 84 nations from 1971-2015.

Employing a dataset of 22 OECD nations spanning 1970-2007, Herzog (2012) found that as nations witness a rise in old-age dependency ratios, those with lower rates of domestic savings, moderate current account deficits, and a greater degree of openness to international trade may actually see a rise in GDP growth rates. The argument

suggests that these countries, with their enhanced access to global capital markets, manage to maintain economic growth even as their old-age dependency ratios significantly increase. These nations, characterized by lower savings rates, can rely on domestic consumption and, notably, foreign investment to counterbalance the decline in worker productivity resulting from the decline of domestic workers. In yet another cross-country analysis, Fukuda and Morozumi (2004) claim that an increase in the old dependence ratio would promote growth by boosting savings of the working-age populace, given that the savings are effectively invested in accumulation of domestic capital. Employing data from Chinese provinces between 1985 and 2005, Li, Li, and Chan (2012) discovered that the ageing of the population positively impacts savings and investments, thereby stimulating economic growth.

By incorporating endogenous and semi-endogenous models of growth, Prettner (2013) illustrated that within the endogenous framework, long-term growth is promoted by the ageing of the population. However, in the semi-endogenous growth model, the impact of population ageing is contingent upon alterations in mortality and fertility. Examining 169 nations spanning 1990 to 2015, Acemoglu and Restrepo (2017) found that ageing populations positively influence economic growth. They propose that the swift implementation of automation technology has contributed to accelerated growth in nations experiencing rapid ageing.

On the other hand, Zhang, Zhang, and Lee (2003) argue that a non-monotonic (nonlinear) relation persists between economic growth and population ageing instead of purely a linear one, with early ageing stages promoting growth due to higher savings but later stages causing decline due to lower capital accumulation and labor force participation. The empirical literature on this nonlinear relationship is limited, with a few exceptions. For instance, Lee and Shin (2019) examined the influence of ageing populations on economic growth using a panel of 142 nations spanning 1960 to 2014 by utilizing panel fixed effect regressions. Their findings indicate that population ageing, proxied by the share of the elderly populace, had negative growth consequences, but this effect was observed only when ageing reached a relatively high level, suggesting a nonlinear relationship. Additionally, they demonstrated that in recent years, population ageing has had a more pronounced negative impact on growth, especially in nations with a higher proportion of elderly individuals.

Similarly, based on a sample of 126 countries from 1970 to 2019, Antonakakis and Workie (2023) unveiled the presence of an Ageing Population Kuznets Curve characterized by an inverted U-shape. They also identified the threshold level formula for this nonlinear effect. Using panel data from OECD countries from 1960 to 2000, cross-country regression and non-parametric kernel estimation show that changes in population and economic growth are linked in a way that looks like an upside-down U. In a separate study, Liu (2013) investigated the impact of population ageing on the economic growth of Chinese provinces using provincial panel data from 1989 to 2009. The findings of their research also indicate the presence of an inverted U-shaped relationship between population ageing and economic growth. They demonstrate that the percentage of the elderly population exhibits a diminishing positive impact on the inter-provincial economic growth rate; however, beyond the inflection point, its influence shifts from positive to negative. Similarly, conducting an empirical investigation using cross-country panel data from 2000 to 2016 by employing Least Square Dummy Variable (LSDV) and Two Stages Least Square (TSLS), Yang, Zheng, and Zhao (2021) also fpund an inverted-U (nonlinear) relationship.

Thus, despite the plethora of literature examining this topic, results remain inconclusive and controversial, with some indicating that an ageing population negatively influences economic growth, while others find a positive impact, yet others demonstrate differing short- and long-term effects, with a few recent exceptions highlighting a non-monotonic relationship. Given that linearity in the relation between economic growth and population ageing serves as a forerunner, with just a handful of recent studies revealing nonlinearity, it remains largely unclear as to when the adverse effect starts to materialize. The current investigation aims to fill this notable research gap by answering the following Research Questions (RQs):

RQ1) Could there be a significant global inverted-U (nonlinear) relation between economic growth and population ageing?

RQ2) If so, is this nonlinear relationship consistent across developed and developing economies?

RQ3) In which ageing-transition-nation category is the threshold level experienced? And does the impact on economic growth get stronger as population ageing deepens?

3. RESEARCH METHODOLOGY

3.1. Classification of Nations Based on Ageing Transition Stages

According to a report by the UN, a country is termed *Super-Aged* when the proportion of people aged 65 and older exceeds 20%; *Aged* if this percentage is 14% or over; and *Ageing* if this proportion is above 7% (World Bank, 2021). Countries with an older population below 7% have been classified as *Potentially Ageing Nations* for purposes of comparison. Given that population ageing is a phenomenon taking place over a period of time wherein nations can transition from one ageing category to the next, we group nations into four transition categories, namely: (i) Aged Nations to Super Aged Nations, (ii) Ageing Nations to Aged Nations (iii) Potentially Ageing Nations to Ageing Nations and (iv) Potentially Ageing nations. The former two categories are designated as nations in the *Advanced stages* of the ageing transition, while the latter two are referred to as nations in the *Initial stages* of the ageing transition. The list of nations in each category is detailed in Table 1.

Table 1. Nation classification based on the stage of their ageing transition.

Advanced transition stages	Nations
Aged nations to super aged nations	Bulgaria, Estonia, Serbia, Germany, Japan, Croatia, Finland, Italy, France, Lithuania, Hungary, Latvia, Czechia, Portugal, Slovenia, Greece, Sweden, Denmark
Ageing nations to aged nations	Albania, Poland, United Kingdom, Australia, Norway, Barbados, Belarus, Canada, Ukraine, Romania, Iceland, Korea, Republic, New Zealand, Russian Federation, Switzerland, United States, North Macedonia, Uruguay
Initial transition stages	Nations
Potentially ageing to ageing nations	Armenia, Bahamas, Costa Rica, Peru, Brazil, Chile, Türkiye, China, Mexico, Colombia, Ecuador, Israel, Jamaica, Mauritius, Morocco, Panama, Thailand, Malaysia
Potentially ageing nations	Azerbaijan, Bahrain, Bangladesh, Belize, Bolivia, Botswana, Egypt, Guatemala, India, Indonesia, Jordan, Mongolia, Nepal, Nigeria, Paraguay, Philippines, Qatar, Uganda

Note: Nations are classified on the basis of the percentage share of their elderly in the total population.

3.2. Data and Empirical Specification

To examine the economic growth implications of population ageing, a dataset has been constructed comprising a panel of the above-mentioned 72 countries spanning three decades (1990 to 2019), extracted from the database of Penn World Tables (PWT 10.1) and World Bank's World Development Indicators (WDI). In further regression, the panel of 72 nations has been split into developed and developing nations. Important to note is that all nations in the advanced stages of the ageing transition are developed nations, except for Barbados and Uruguay, resulting in a sample of 35 developed nations, while all nations in the initial stages of the transition are developing economies, except for Israel, resulting in a sample of 37 developing nations. Following the augmented-Solow growth framework (Mankiw, Romer, & Weil, 1992; Solow, 1956), we estimate the following Ageing Population Kuznet's Curve (APKC) model as proposed by Antonakakis and Workie (2023):

$$\Delta lnY_{it} = \alpha_0 + \beta_1 lnY_{it-1} + \beta_2 lnK_{it-1} + \beta_3 lnH_{it-1} + \beta_4 lnPop_{it-1} + \gamma_1 POPAG_{it-1} + \gamma_2 POPAG^2{}_{it-1} + \gamma_3 \Delta POPAG_{it} + \delta R_i + \zeta_t + \varepsilon_{it} \quad (1)$$

where, ΔlnY_{it} is the 5–year non-overlapping and consecutive average growth rate of the log of real GDP per capita (PPP) in constant 2017 international dollars in country i (where i = 1, 2, ...72), and time t (where t = 1990-94..., 2015-19, i.e. six 5-year non-overlapping sub-periods). By using 5-year non-overlapping average growth rates the impact of fluctuations in the business cycle is mitigated.

α_0 is a constant. The lag of lnY_{it} is incorporated to address conditional convergence. To capture the effects of initial values and prevent potential endogeneity, we incorporate all independent variables, except those in first differences, with their initial lag (Antonakakis & Workie, 2023; Lee & Shin, 2019). Turning to the main variables of

interest, $POPAG_{it-1}$ and $POPAG^2{}_{it-1}$ denote the ageing population measure, the former capturing the long run relation at level, while the latter is incorporated to capture the nonlinear relation via the quadratic term. Population ageing is proxied by: (a) Share of the elderly in the population $(POPAG_{it-1})$ as in Equation 1 and (b) Old age dependence ratio $(OLDEP_{it-1})$: the proportion of older individuals 65 years and above to the working age populace between 15-64 years, besides including its square term $(OLDEP^2{}_{it-1})$ in Equation 2. $\Delta POPAG_{it}$ denotes the first difference of the ageing proxy capturing any potential short-run effects of ageing population on economic growth.

$$\Delta lnY_{it} = \alpha_0 + \beta_1 lnY_{it-1} + \beta_2 lnK_{it-1} + \beta_3 lnH_{it-1} + \beta_4 lnPop_{it-1} + \gamma_1 OLDEP_{it-1} + \gamma_2 OLDEP^2{}_{it-1} + \gamma_3 \Delta OLDEP_{it} + \delta R_i + \zeta_t + \varepsilon_{it} \quad (2)$$

lnK_{it} denotes the log of capital stock at constant 2017 prices in US$ millions, lnH_{it} is the log of human capital index derived from years of schooling and returns to education while $lnPop_{it}$ is the log of total population in millions.

R_i is a vector of regional dummy variables based on Penn World tables regional classification comprising: North America, Oceania, Asia, South America, Europe and Africa. Following Acemoglu and Restrepo (2017) and Eggertsson et al. (2019) we control for regional dummies as opposed to country fixed-effects, due to (a) widespread regional heterogeneity in demographic structure and (b) critiques related to the use of country fixed-effects in cross-country growth regressions. ζ_t entails time fixed-effects to account for time-varying differences among countries. ε_{it} is the error term.

3.3. Analysis Procedure

Table 2 presents the analysis procedure adopted for appropriate model selection. The Breusch-Pagan Lagrange Multiplier (LM) test has been adopted to assess the suitability of using a Random Effects Model (REM) in comparison to the Pooled Ordinary Least Square (POLS) for both equations (Equation 1: Model 1 and Equation 2: Model 2). In each case, the LM test significantly rejects the null hypothesis of no random effect (at the 1% significance level), demonstrating that a REM is preferable. The Modified Wald test is used to examine group-wise heteroscedasticity, which was found to be significantly present at the 1% level, the presence of which was controlled for by adopting robust standard errors. Next, to check the appropriateness of the Fixed Effect Model (FEM) v/s the REM, the Hausman test for post-estimation had to be employed. However, because robust standard errors are used, the Sargan-Hansen test is preferable. The findings of the post-estimation test significantly refuted the null hypothesis of the suitability of utilizing REM and showed that FEM is preferable over REM. Stata (v.16) software is used to analyze the data.

Table 2. Tests for appropriate model selection.

Tests	Based on model (1) with POPAG [Equation 1]	Based on model (2) with OLDEP [Equation 1]
Breusch-Pagan LM test	12.06*** (0.000)	20.63*** (0.000)
Modified Wald test	1776.88*** (0.000)	8078.95*** (0.000)
Sargan-Hansen statistic	66.05*** (0.000)	59.67*** (0.000)

Note: *** Significant at the 1% level.

4. RESULTS

4.1. The Evidence of Nonlinearities

Results of the fixed effect estimations as outlined in Equation 1 and 2 present an answer to RQ1: *Could there be a significant global inverted-U (Nonlinear) relation between economic growth and population ageing*, and are displayed in Table 3.

First, let's look at the results for all 72 countries. The initial per capita GDP coefficients [-0.043 (Model 1) and -0.040 (Model 2)] are significantly negative at the 1% level. This shows that countries with higher incomes grow more slowly than countries with lower incomes. The coefficients of physical capital stock (0.012 and 0.010 in the respective models) are significantly positive, highlighting their positive influence on economic growth. Nations with more physical capital accumulation have a faster growth rate. In contrast, though the signs of the coefficients of human capital and population are appropriate, they remain insignificant in the present study.

Moving on to the main variables we are interested in, Model 1's results show that the difference term in the share of older adults has a coefficient of 0.025. This shows that in the short term, a growing number of older people has a positive effect on economic growth at the 1% significance level. However, in the long run, the baseline coefficient of old share (0.003) is significantly positive at the 10% level, whereas it's quadratic coefficient (-0.0001) is significantly negative at the 5% level. This suggests that there is a nonlinear relationship with a threshold effect: as the proportion of older adults in the populace increases, economic growth also initially increases. However, once the elderly population share reaches a maximum limit, it starts having adverse effects on economic growth, leading to a decline in growth, suggesting the presence of a non-monotonic relationship in the long run.

Our findings of this non-monotonic relationship remain robust, as the old age dependency ratio is proxied by the share of the elderly in Model 2. As the old-age dependency ratio increases, economic growth also significantly increases initially. However, a significantly negative quadratic coefficient (-0.00004) suggests that once the old-age dependency ratio reaches a maximum limit, it starts having adverse effects on growth, leading to a decline in growth.

4.2. Assessing the Non-linear Impact among Developed and Developing Nations

Next, by splitting the sample between (35) developed and (37) developing economies, we attempt to answer RQ2: *Whether the non-linear relationship is significantly consistent across both developed and developing economies?*

The results presented in Table 3 (Models 3 to 6) suggest that a significant nonlinear relationship exists between economic growth and population ageing in the cases of the coefficients of the quadratic terms of both the proxies: old share (-0.0002) and old age dependency (-0.00007), respectively, in developed economies, which comprise nations transitioning from Ageing to Aged and those from Aged to Super-Aged, since improving longevity and declining birth rates arose foremost among the developed nations. However, in the developing economies, which mainly include Potentially-Ageing nations and those transitioning from Ageing to Potentially-Ageing, i.e., nations in the initial stages of their ageing transition, only a significant positive short run effect is observed in both cases, old share (0.034) and old dependency ratios (0.022), respectively, with no evidence of a long-run nonlinear relation.

Table 3. Impact of ageing population on (5-year average non-overlapping) economic growth.

Variables	Full sample of 72 nations		Developed nations		Developing nations	
	(1)	(2)	(3)	(4)	(5)	(6)
Log real GDP per worker	-0.042*** (0.007)	-0.040*** (0.009)	-0.060*** (0.016)	-0.056*** (0.012)	-0.038*** (0.011)	-0.037*** (0.011)
Log physical capital	0.012* (0.006)	0.010*** (0.005)	0.004** (0.015)	0.000** (0.000)	0.011 (0.009)	0.012 (0.009)
Log human capital	0.011 (0.012)	0.012 (0.012)	0.010 (0.038)	0.020 (0.038)	0.024** (0.012)	0.025** (0.012)
Log population	-0.018 (0.013)	-0.020 (0.013)	-0.064* (0.038)	-0.053* (0.030)	-0.035** (0.014)	-0.037** (0.015)
Old share	0.003* (0.001)		0.006** (0.002)		0.005 (0.003)	
Old share^2	-0.000** (0.000)		-0.000*** (0.000)		0.000 (0.000)	
Δ Old share	0.025*** (0.009)		0.007 (0.011)		0.034* (0.020)	

Variables	Full sample of 72 nations		Developed nations		Developing nations	
	(1)	(2)	(3)	(4)	(5)	(6)
Old dependency		0.001* (0.000)		0.003** (0.001)		0.002 (0.001)
Old dependency^2		-0.000** (0.000)		-0.000** (0.000)		0.000 (0.000)
Δ Old dependency		0.014*** (0.004)		0.006 (0.006)		0.022** (0.011)
Constant	0.340*** (0.074)	0.331*** (0.077)	0.867 (0.271)	0.739 (0.274)	0.356*** (0.080)	0.339*** (0.085)
Obs	350	350	167	167	183	183
Number of countries	72	72	35	35	37	37
R-squared	0.552	0.555	0.617	0.606	0.623	0.631
Adjusted R-squared	0.412	0.416	0.474	0.460	0.488	0.499
F test Prob > F	F(12,266) =4.68 0.000	F(12,266) =4.65 0.000	F(11,121) =7.6 0.000	F(11,121) =6.54 0.000	F(12,134) = 4.1 0.000	F(12,134) = 3.8 0.000

Note: *** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level.
Numbers in parentheses indicate robust standard errors to control for heteroskedasticity.

4.3. Population Ageing Deepening and Intensification of the Impact on Growth: Identification of the Threshold Level

The presence of a global nonlinear relation between population ageing and economic growth among developed nations, but the insignificance of the same among developing nations suggests the presence of a threshold level below (above) which ageing populations could promote (adversely affect) economic growth. Thus we seek to analyze RQ(3): *In which ageing-transition-nation category is the threshold level experienced? And does the impact on economic growth get stronger as population ageing deepens?* Based on the coefficients $\hat{\gamma}_1$ and $\hat{\gamma}_2$ estimated from Equation 1 and 2, Antonakakis and Workie (2023) in their study adopted a method to calculate the threshold levels below (above) which ageing populations could promote (adversely affect) economic growth as follows:

$$Threshold = \frac{\hat{\gamma}_1}{-2\hat{\gamma}_2} \qquad (3)$$

According to Equation 3, the calculated threshold level for the share of the elderly in the sample of 72 nations is 13.83%, and for the old age dependency ratio, it is 20.13%. Nevertheless, for further elucidation on these threshold levels, the marginal effects at various increments of the elderly population share and old age dependency ratio, respectively, have been delineated.

Table 4. Marginal effects of old age share on economic growth.

Old share at (%)	Delta-method		z	P>|z|	[95% conf. interval]	
	Margin	Std. error				
1	0.081	0.020	4.03	0.000***	0.041	0.120
2	0.072	0.017	4.17	0.000***	0.038	0.106
3	0.063	0.014	4.37	0.000***	0.035	0.092
4	0.055	0.011	4.67	0.000***	0.031	0.078
5	0.046	0.008	5.15	0.000***	0.028	0.063
6	0.037	0.006	6.05	0.000***	0.025	0.049
7	0.028	0.003	8.32	0.000***	0.022	0.035
8	0.020	0.001	19.35	0.000***	0.018	0.022
9	0.011	0.002	4.87	0.000***	0.006	0.016
10	0.002	0.005	0.57	0.567	-0.007	0.012
11	-0.005	0.007	-0.74	0.462	-0.021	0.009
12	-0.014	0.010	-1.36	0.174	-0.035	0.006
13	-0.023	0.013	-1.73	0.084*	-0.049	0.003
14	-0.031	0.016	-1.96	0.049**	-0.063	-0.000
15	-0.040	0.018	-2.13	0.033**	-0.077	-0.003

Old share at (%)	Delta-method		z	P>|z|	[95% conf. interval]	
	Margin	Std. error				
16	-0.049	0.021	-2.26	0.024**	-0.091	-0.006
17	-0.057	0.024	-2.36	0.018**	-0.106	-0.009
18	-0.066	0.027	-2.43	0.015**	-0.120	-0.012
19	-0.075	0.030	-2.50	0.013**	-0.134	-0.016
20	-0.083	0.032	-2.55	0.011**	-0.148	-0.019
21	-0.092	0.035	-2.59	0.010**	-0.162	-0.022
22	-0.101	0.038	-2.63	0.009***	-0.176	-0.025
23	-0.110	0.041	-2.66	0.008***	-0.191	-0.029
24	-0.118	0.044	-2.69	0.007***	-0.205	-0.032
25	-0.127	0.046	-2.72	0.007***	-0.219	-0.035
26	-0.136	0.049	-2.74	0.006***	-0.233	-0.038
27	-0.144	0.052	-2.76	0.006***	-0.247	-0.041
28	-0.153	0.055	-2.78	0.006***	-0.261	-0.045
29	-0.162	0.058	-2.79	0.005***	-0.275	-0.048
30	-0.170	0.060	-2.81	0.005***	-0.290	-0.051

Note: *** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level.

For instance, according to Table 4, at around 7% of population ageing (a nation transitioning from being Potentially Ageing to Ageing) a one percentage point increase in population ageing leads to a significant increase in the 5-year GDP per capita growth rate by 0.029 percentage points. As the share of the elderly population continues to rise and touches around 11% of the population, positive effects turn negative, nevertheless remaining insignificant, until the share reaches around 13%, which represents the threshold level, wherein a percentage point increase in population ageing results in a statistically significant reduction in economic growth by 0.023 percentage points. This is the turning point from which an Ageing nation transitions to an Aged nation. As the share of the elderly rises further and the nation transitions into a Super Aged nation with an elderly share of more than 20%, the negative effects of an ageing population on economic growth continue to grow in magnitude while remaining statistically significant. In a nutshell, our findings suggest that the influence of ageing populations on economic growth is conditional on the level of the ageing population.

Similar conclusions can be derived from the marginal effects of old age dependency on economic growth presented in Table 5. When the old age dependency ratio is under 14%, an escalation in this ratio yields a notably favorable influence on economic growth. However, as the dependency ratio increases, although the marginal effects become negative, they lack statistical significance. Nevertheless, upon reaching approximately 20%, each percentage point increase in the old age dependency ratio results in a statistically significant reduction of 0.029 percentage points in 5-year economic growth. Moreover, as the dependency ratio persists in its ascent, the detrimental impact on economic growth intensifies.

Table 5. Marginal effects of old age dependency on economic growth.

Old dependency at (%)	Delta-method		z	P>|z|	[95% conf. interval]	
	Margin	Std. error				
1	0.091	0.026	3.50	0.001***	0.039	0.142
2	0.084	0.023	3.57	0.000***	0.038	0.131
3	0.078	0.021	3.66	0.000***	0.036	0.120
4	0.072	0.019	3.76	0.000***	0.034	0.109
5	0.065	0.016	3.89	0.000***	0.032	0.099
6	0.059	0.014	4.07	0.000***	0.030	0.088
7	0.053	0.012	4.30	0.000***	0.028	0.077
8	0.046	0.010	4.64	0.000***	0.026	0.066
9	0.040	0.007	5.19	0.000***	0.024	0.055
10	0.033	0.005	6.16	0.000***	0.023	0.044
11	0.027	0.003	8.44	0.000***	0.021	0.034
12	0.021	0.001	17.32	0.000***	0.018	0.023

Old dependency at (%)	Delta-method		z	P>|z|	[95% conf. interval]	
	Margin	Std. error				
13	0.014	0.001	8.93	0.000***	0.011	0.018
14	0.008	0.003	2.23	0.027**	0.000	0.016
15	0.002	0.006	0.35	0.724	-0.009	0.014
16	-0.004	0.008	-0.51	0.613	-0.020	0.012
17	-0.010	0.010	-1.00	0.319	-0.031	0.010
18	-0.016	0.012	-1.32	0.190	-0.042	0.008
19	-0.023	0.015	-1.54	0.126	-0.053	0.006
20	-0.029	0.017	-1.70	0.091*	-0.064	0.004
21	-0.036	0.019	-1.83	0.069*	-0.074	0.002
22	-0.042	0.022	-1.93	0.056*	-0.085	0.001
23	-0.048	0.024	-2.01	0.046**	-0.096	-0.000
24	-0.055	0.026	-2.07	0.040**	-0.107	-0.002
25	-0.061	0.028	-2.13	0.035**	-0.118	-0.004
26	-0.067	0.031	-2.18	0.031**	-0.129	-0.006
27	-0.074	0.033	-2.22	0.028**	-0.140	-0.008
28	-0.080	0.035	-2.26	0.025**	-0.151	-0.010
29	-0.086	0.038	-2.29	0.023**	-0.161	-0.011
30	-0.093	0.040	-2.31	0.022**	-0.172	-0.013
31	-0.099	0.042	-2.34	0.020**	-0.183	-0.015
32	-0.106	0.044	-2.36	0.019**	-0.194	-0.017
33	-0.112	0.047	-2.38	0.018**	-0.205	-0.019
34	-0.118	0.049	-2.40	0.017**	-0.216	-0.021
35	-0.125	0.051	-2.42	0.017**	-0.227	-0.023

Note: *** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level.

5. DISCUSSION

Population ageing exerts a significant impact on the macroeconomy. This study investigated the impact of population ageing on economic growth by proxying the growth rate of GDP per capita for economic growth in line with previous empirical growth models (Antonakakis & Workie, 2023; Lee & Shin, 2019; Papapetrou & Tsalaporta, 2020). In contrast to majority of the prior studies, which assumed a linear relationship between population ageing and economic growth (Bawazir et al., 2020; Eggertsson et al., 2019; Fukuda & Morozumi, 2004; Herzog, 2012; Huang et al., 2019; Ismail et al., 2016; Li & Zhang, 2015; Lindh & Malmberg, 2009; Maestas et al., 2023; Mamun et al., 2020; Miri et al., 2019; Park et al., 2012; Ruidong, 2018; Uddin et al., 2016; Wongboonsin & Phiromswad, 2017; Zhao et al., 2018), our study analyses a non-linear relation. Our findings of a non-monotonic relation, trace similarities to those of a few researchers who have also found evidence of the same (Antonakakis & Workie, 2023; Lee & Shin, 2019; Liu, 2013; Yang et al., 2021; Zhang et al., 2003).

In consonance with Hyun-Hoon Lee et al. (2013), our study unravels long- and short-run growth implications by estimating the coefficients at level and first-difference, respectively. Fixed effects regressions indicate, that, in the short-run, ageing populations exert a positive effect on economic growth. Nevertheless, in the long-run, a nonlinear relation exists. Similar to the findings of Lee and Shin (2019), our study found that the nonlinear relation is significant only among developed nations compared to developing nations, as the former are at the advanced stages of the ageing transition. In other words, the adverse impact on economic growth intensifies, as population ageing deepens. Our findings of the threshold level below (above) which population ageing positively (adversely) affects economic growth are in line with the research by Antonakakis and Workie (2023), who also conducted analysis using two proxies of population ageing: the share of older adults in the population and the old age dependency ratio, to ensure robustness of the results. Our study goes a step forward by finding out that the nations transitioning from being Ageing to Aged, experience the threshold level. Given these findings, the next section puts forth practical policy implications that policymakers can adopt during the buffer period of transition to prepare for and minimize the adverse impact of population ageing.

6. CONCLUSION

The major contribution of this study lies in investigating a long-run, non-linear relation between population ageing and economic growth in a panel of nations belonging to different stages of the ageing transition. As the proportion of older adults in the population increases, economic growth initially increases; however, once the elderly population share reaches a maximum limit, it starts having adverse effects on economic growth. The nonlinear impact being pronounced only among developed nations, which are primarily at the advanced stages of their ageing transition, points to another contribution: that the detrimental effect on economic growth gets stronger as population ageing deepens. The period of transition available to nations in the initial stages of their ageing transition, before the proportion of their older population reaches the threshold level, gives decision-makers an opportunity to gear up and plan appropriately for this transition. Policy frameworks greatly influence the growth implications of an ageing populace. The obstacle, as explored by Harper (2023), involves not so much the shifting demography but rather the structures and policies that shape the aftermath.

Following are a few suggestions that nations can adopt to minimize the adverse impact: Firstly, many nations are adopting the ideal approach to increased longevity, which involves increasing the proportion of years of work and retirement age. Secondly, the compression of morbidity and medical expenses towards a shorter duration in later life and initiatives towards healthy ageing and improvements in the physical and emotional health of older individuals will ease the strain on the healthcare and social insurance programs, encouraging individuals to stay employed longer. This gain in output from the direct contribution of healthy older individuals towards economic efficiency, by being employed for a greater time is termed the *Silver Demographic Dividend* (Naohiro, Mansor, Lee, Abrigo, & Aris, 2021). Thirdly, since ageing populations inevitably lower the availability of labor, the obvious solution would be to devote resources to capital machinery that enhances labor productivity. However, migration from the developing world to the developed world could alleviate the strain on each nation category concerning the working-age population surplus and shortage situations posed by population ageing. Fourth, greater longevity may encourage workers to save more throughout their careers to maintain a good quality of life post-retirement, which will help the economy thrive. Finally, in light of the current knowledge economy, businesses can encourage older employees to stay employed and benefit from their experience and reliability. If facilitated by good policies, aging populations may open up new possibilities for flourishing entrepreneurial and innovative thinking. Future research in this area can be directed towards analyzing the impact of population ageing on economic growth among low-, middle-, and high-income nations, given projections that many countries are becoming old before they become rich. Besides, another area of investigation having great implications for economic growth is the *Silver Economy* which refers to the economic opportunities and challenges associated with ageing populations, particularly focusing on the consumption, production, and investment patterns of older adults. It encompasses various industries and sectors that cater to the needs and preferences of seniors, including healthcare, leisure, housing, finance, and technology. A multi-pronged approach to this area is the need of the hour to reap the silver dividend from the silver economy.

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