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Does human capital mitigate the deflationary effects of aging?

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ABSTRACT

Existing studies have well documented the economic consequences of population aging and its impact on inflation. However, the role of human capital in the nexus between aging and inflation is underexplored, particularly in Emerging Markets and Developing Economies (EMDEs). This study uses data from 123 countries, including 89 EMDEs, to investigate how human capital shapes the aging–inflation nexus. Alongside the use of the human capital index (HCI) from the Penn World Table, the study uses long-run historical education attainment data to construct a targeted measure of elderly human capital, i.e., years of schooling of the elderly. The finding reveals that aging is deflationary, and higher human capital and elderly human capital are significantly associated with weaker deflationary pressure. The study identifies critical thresholds. For instance, when HCI $\approx$ 3.3 for EMDEs, aging becomes inflationary rather than deflationary; similarly, for our targeted measure, the turning point occurs at $\approx$ 5.4 years of schooling among the elderly. By analyzing the channel, we find that the association is concentrated among the educated elderly labor force, consistent with educated elderly participating as active economic contributors rather than purely dependent consumers. Findings are robust to splitting the sample within EMDEs, alternative measures of aging, additional controls, and alternative estimation method, i.e., System Generalized Method of Moments (GMM). The study's findings highlight important policy implications, including the need for lifelong learning policies to ensure macroeconomic resilience amid population aging.

1. Introduction

Existing studies (e.g., Bloom et al., 2010; Heijdra & Reijnders, 2016) highlight the benefits of investing in human capital for sustaining economic growth and labor productivity in aging societies. However, it is unknown whether such investments can also mitigate the deflationary pressures associated with population aging. The present study addresses this gap by focusing on emerging markets and developing economies (EMDEs) for two main reasons. First, EMDEs display diverse demographic trends compared with advanced economies: while some are experiencing rapid population growth, others are already undergoing rapid aging (United Nations, 2024). Second, advanced economies already have higher levels of human capital; studying EMDEs is especially relevant from a policy perspective, as these countries are still building and improving their human capital.

Theoretical frameworks by Thøgersen (2015) and Choi and Shin (2015) suggest that population aging may boost physical capital accumulation by increasing savings and lowering interest rates. Building on this, Heijdra and Reijnders (2016) demonstrate that

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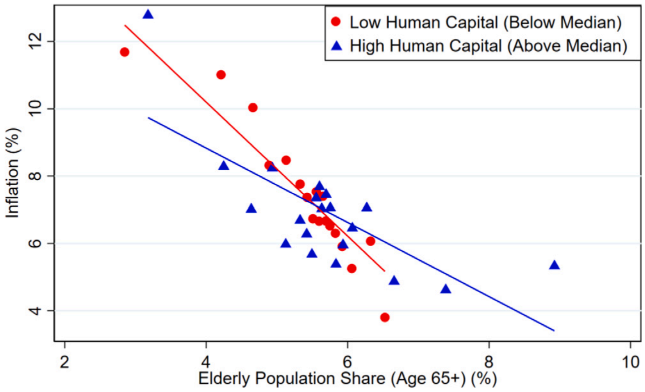


Fig. 1. Role of Human capital in the Aging–Inflation Nexus (EMDEs).
Notes: Figure is based on 89 EMDEs in Table A.1. The plotted values represent bin-specific means adjusted for country fixed effects, isolating within country variation.
Source: Authors' own illustration.

biological and economic longevity boosts increase the human capital stock more than the physical capital stock, leading to a fall in the rental rate of human capital and a rise in the interest rate. Such demographic shocks allow agents to increase years of schooling and delay retirement by reducing leisure time. This shift in human capital accumulation has direct ramifications for inflationary outcomes through aggregate demand, particularly for EMDEs.[3] Higher human capital implies higher lifetime income and consumption smoothing, positively affecting aggregate demand and mitigating deflationary "secular stagnation" associated with population aging (Summers, 2016). Therefore, the present study carefully considers only investigating the role of human capital in the relationship between aging and inflation for EMDEs.

To provide a preliminary motivation for our empirical analysis, we investigate whether the effects of population aging on inflation depend on human capital. Fig. 1 presents a binned scatterplot of the inflation rate against population aging (Age65), splitting EMDEs into two groups based on the median Human Capital Index.

Fig. 1 reveals a structural heterogeneity. While both groups confirm the negative relationship between aging and inflation, consistent with the secular stagnation hypothesis, in which aging dampens aggregate demand and leads to deflationary pressure (Anderson et al., 2014; Summers, 2016), the magnitude of this effect differs substantially across groups. The low-human capital group shows a steep negative slope, indicating that in countries with lower skill and knowledge bases, population aging exerts a severe drag on the price level. In contrast, the high human capital group displays a significantly flatter slope. This finding supports our core hypothesis that higher human capital acts as a productivity buffer, mitigating the deflationary pressure of population aging. These stylized facts challenge the assumption of uniform aging effects and motivate further analysis.

We compiled data from 123 countries between 1990 and 2023, including 89 EMDEs and 34 AEs, to examine the association between aging and the human capital index. The results suggest that higher human capital is associated with weaker deflationary pressure, and with an inflationary effect at higher levels of human capital (HCI). To deepen the analysis, we construct and employ a novel, targeted measure of elderly human capital: the years of schooling of the elderly population. We find similar results: the deflationary pressure of aging weakens and even becomes inflationary as the years of schooling of the elderly increase. The results are consistent and robust to splitting the sample within EMDEs, replacing aging measures, adding additional controls, and an alternative method of estimation (i.e., system GMM). To explain the possible channel through which elderly human capital weakens the deflationary pressure of aging, we use two regions, one with a less educated elderly labor force participation and another with more educated elderly labor force participation, and the findings reveal that the moderating association is concentrated among the more educated elderly, consistent with their contributing positively to the economy. These findings also highlight the necessity of "quality" over "quantity" in aging labor markets.

The paper is organized as follows. Section 2 formulate research hypothesis along reviewing existing literature. Section 3 discuss the data and methodology along with construction of our key variable. In Section 4, we present the results along with a discussion of possible mechanism and robustness checks. Section 5 concludes the study with policy implication and recommendation. Finally, Section 6 outlines the key limitations of our study.

2. Research hypothesis

To formulate the research hypothesis of the present study, we discuss the role of human capital by outlining its relationship with population aging and inflation. We proceed in three steps: we first review how aging affects inflation (Section 2.1), then how

[3] Additionally, between 1950 and 2024, EMDEs experienced more rapid growth in life expectancy than advanced economies. See World Bank data on Life expectancy at birth, total (years).

human capital affects inflation (Section 2.2), and finally how human capital and aging are linked (Section 2.3), before integrating these strands into a unifying framework from which our hypothesis follows.

2.1. Population aging and inflation

Population aging reduces consumption and investment.[4] Lee et al. (2024) argue that consumption will decline faster than investment because population aging reduces the labor supply, necessitating offsetting investments. As a result, net savings increase, pushing natural interest rates downward. If monetary policy fails to internalize the downward pressure from population aging on the natural interest rate, disinflationary pressures set in Koester et al. (2021). Nevertheless, the central bank does not necessarily respond quickly to changes in the natural rate induced by population aging, as these changes occur slowly and are difficult to detect (Beyer & Wieland, 2019).

Consistent with this macroeconomic logic, a broad body of empirical work finds that aging is deflationary. Yoon et al. (2018) found that aging is deflationary, driven by mechanisms such as reduced labor force participation and lower economic growth prospects. Broniatowska (2019) and Gajewski (2015) also note that aging is deflationary in developed countries, driven by increased savings and reduced consumption as life expectancy rises. Beyond these economic channels, a parallel strand emphasizes political mechanisms. Vlandas (2018) established that aging is deflationary due to the role of political mechanisms: as older age groups grow, they prefer lower inflation, and political parties ensure that. Katagiri et al. (2020) also highlight the role of political mechanisms. The study argued that population aging is inflationary when a declining fertility rate causes aging, whereas it is deflationary when aging is induced by rising life expectancy. He and Li (2020) suggest that aging affects the relationship between life expectancy and economic growth, which, in turn, can influence inflation via aggregate demand.

This consensus is not universal, however. A few studies, including Juselius and Takáts (2021), find that older dependent populations are inflationary because they consume more than they produce, thereby increasing aggregate demand. Most of the literature mentioned above exclusively focuses on developed countries. Mazumder and Diwakar (2025a) confirmed that population aging is deflationary across developed and developing countries. They argued that aging reduces inflation by lowering aggregate demand, mainly due to lower fertility rates and slower population growth in developing countries. There are a few studies (Antonova & Vymyatnina, 2018; Mazumder & Diwakar, 2025b; Rai & Garg, 2025) that focus on developing countries. However, existing studies have largely ignored the role of human capital in the relationship between aging and inflation, a gap that the present study seeks to address. This omission is the first of two building blocks for our hypothesis; we turn next to how human capital itself shapes inflation.

2.2. Human capital and inflation

According to Lucas (1988), increasing human capital can raise productivity, potentially leading to deflation as the supply of goods and services increases. Basu et al. (2012) highlight that, initially, economic agents (or the labor force) may spend more on enhancing human capital through education and training, leaving less time for the production of goods. However, over time, increased investment in human capital raises labor productivity as the labor force becomes more skilled and efficient. As a result, deflationary pressure sets in from lower production costs and technological advancements.

Human capital shapes not only the level of prices but also an economy's resilience to inflation. Laguna and Sanso (2020) demonstrate that wage-setting, based on wages per unit of human capital rather than per hour helps mitigate the negative impact of inflation. Because skill and knowledge based economies are more resilient to the adverse effects of inflation on growth. Moreover, a recent study by Mbewe et al. (2025) found that human capital development also reduces the distributional effects of high inflation. The study shows that higher inflation worsens economic instability and inequality. However, higher human capital creates a resilience buffer to neutralize this impact. Taken together, Sections 2.1 and 2.2 establish that aging and human capital each influence inflation. What remains is to connect them to show why the two forces are not independent.

2.3. Human capital and aging

It is well established that increasing life expectancy and declining fertility are the two main factors driving population aging (Nagarajan et al., 2021). Crucially, both of these drivers also act on human capital, which is what links the two literatures reviewed above. For instance, increasing life expectancy[5] due to improved health conditions increases the number of years of schooling (Bloom et al., 2003). The parents are incentivized to increase the years of schooling. As a result, human capital increases.

On the other hand, declining fertility subsequently reduces family size. The decline in the child dependency ratio enables parents to finance more investments in their children's schooling (Kelley & Schmidt, 2005). Heijdra and Reijnders (2016) also note that greater human capital investment can mitigate the adverse economic impacts of population aging.

While a growing body of work documents how demographic aging influences inflation (e.g., Juselius & Takáts, 2021; Katagiri et al., 2020; Mazumder & Diwakar, 2025b, 2026; Yoon et al., 2018), and how human capital accumulation shapes productivity and

[4] As a result, aging slows down economic growth (Aigner-Walder & Döring, 2012; Bloom et al., 2010; Lisenkova et al., 2013).

[5] For broader discussion on life expectancy and education, refer to Cervellati and Sunde (2015). They document significant effects of life expectancy on schooling and population dynamics.

price dynamics (Basu et al., 2012; Lucas, 1988), few studies examine these three factors jointly. Although demographic transition and human capital are closely linked (Bloom et al., 2003; Heijdra & Reijnders, 2016), systematic cross-country empirical work analyzing how human capital modulates the impact of aging on inflation, particularly in emerging markets remains limited. Before stating the hypothesis, we integrate the preceding channels into a single framework that also reconciles them with the experience of advanced economies.

2.4. A unifying framework: Demand, supply, and labor-market channels

To integrate the mechanisms above into a testable structure, we organize the theoretical channels through which human capital conditions the aging–inflation nexus into three distinct strands. (i) The demand-side channel: educated elderly cohorts accumulate higher lifetime earnings and pension wealth and therefore sustain consumption in retirement, counteracting the aggregate-demand contraction that drives the deflationary effect of aging (Summers, 2016; Yoon et al., 2018). (ii) The supply-side channel: higher human capital raises productivity and lowers unit production costs, which may itself exert disinflationary pressure (Basu et al., 2012; Lucas, 1988); this channel works in the opposite direction to the demand channel. (iii) The labor-market channel: educated elderly remain in the workforce longer, simultaneously maintaining wage income (a demand effect) and productive capacity (a supply effect).

Which channel dominates is an empirical question. We hypothesize that in EMDEs the demand-side and labor-market participation effects dominate the supply-side effect, for two reasons. First, EMDEs operate further from the technological frontier, so the productivity driven disinflationary channel is comparatively weak. Second, in labor surplus EMDE settings the marginal supply effect of additional elderly participation is partly absorbed by existing slack, whereas the income and demand effects are relatively strong because elderly consumption is concentrated in services and healthcare with relatively inelastic supply. This framework also clarifies why several high-human-capital advanced economies (Japan, Germany, Italy, South Korea) have nonetheless experienced persistent disinflation: there, near saturated human capital, powerful precautionary saving motives, low natural interest rates, and demographic headwinds to investment (the secular stagnation forces of Goodhart & Pradhan, 2020; Summers, 2016) dominate, so that human capital mitigates but does not reverse the deflationary effect. Our EMDE focus is precisely where the marginal returns to human capital are highest and the turning point can, for a small set of economies, be reached. These considerations lead directly to our central hypothesis.

Hypothesis 1. Higher human capital can reduce the deflationary pressure of population aging.

The above hypothesis can be accepted upon finding that, as human capital increases, the deflationary pressure from aging decreases.

3. Data and methods

3.1. Key variables

3.1.1. Aggregate human capital index

The human capital index (HCI) from Penn World Table (PWT 10.1) (Feenstra et al., 2015) is our primary mediating variable for the overall measure of skill and knowledge in the economy. The HCI is constructed using a standard Mincerian framework, which combines years of schooling data from Barro and Lee (2013) with predetermined rates of return to education from Psacharopoulos (1994). It is common practice for empirical studies (such as Ahmad & Khan, 2019; Siskova et al., 2023) to use HCI as a broad proxy for the total knowledge and skill stock of the working-age population.

3.1.2. Targeted measure: Elderly human capital

A key contribution of our study is the estimation of elderly human capital (Edu_Elderly), i.e., the years of schooling of the elderly population. This helps us capture demographic-specific interaction with inflation. We estimate elderly human capital by using the long-run educational attainment datasets of Lee and Lee (2016). We utilize a cohort-mapping technique inspired by the longitudinal reconstructions found in Barro and Lee (2010). We link the elderly cohort observed in a given year back to their period of formal schooling. For instance, an older adult in 1995 must have completed their schooling in 1910 (assuming the person is 100 years old) or 1945 (assuming the person is 65 years old). By averaging the years of schooling between 1910 and 1945, we obtain the elderly's human capital (years of schooling) in 1995 for the specific country. We replicate this across the sample period and countries to get a panel-consistent elderly human capital variable.

Following Barro and Lee (2013), only the education level of the adult population aged 15 or above is considered. This threshold accurately reflects the prevalence of primary and early secondary schooling among the elderly in 1995, who were born during the era (1895–1930) in which our cohorts were born. Consequently, we treat elderly human capital in the year as a "reference" of the historical education system. Using the Lee and Lee (2016) dataset, which provides 5-year schooling data back to 1870, we calculate the elderly human capital (Edu_Elderly) variable in the current year as follows:

$$Edu\_Elderly_{i,t} = \frac{1}{36} \sum_{k=50}^{85} S_{i,t-k}$$

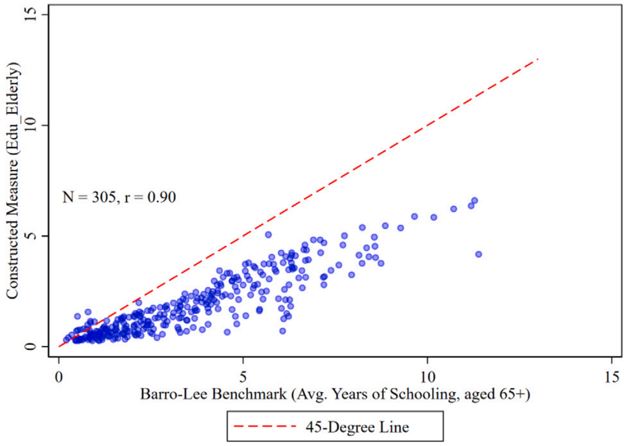


Fig. 2. Validation: Constructed Measure vs. Barro-Lee (65+).
Source: Authors' illustrations using the constructed measure and Barro and Lee (2013) dataset.

Where i denotes country and k denotes time lag (in years), and $S_{i,t-k}$ represents the historical average years of schooling for the 15+ population in country i. The relevant historical schooling window spans from $t-85$ (when a 100-year-old was 15) to $t-50$ (when a 65-year-old was 15). This 36-year rolling average captures the full educational spectrum of the surviving elderly population. While our $Edu\_Elderly_{i,t}$ measure uses the same underlying source data as the PWT, this backward-mapping isolates the specific age bracket necessary to test our aging–inflation hypothesis.[6]

3.1.3. Validation of elderly human capital variable

Since measuring elderly human capital is a key contribution of our paper, a validation test is necessary using the existing proxy variables. For this, we collate variables on the years of schooling for individuals aged 65–69, 70–74, and 75+ from Barro and Lee (2013). By aggregating them, we obtain a comparable variable: the average years of schooling of the aged 65+. There are only 439 overlapping country-year observations in our sample. In Fig. 2, we show the validation test using scatterplots of our constructed variable, Edu_Elderly, and the average years of schooling for age 65. This suggests the strong correlation of between the variables. The scatterplot confirms that our measure closely tracks the Barro and Lee (2013) benchmark, validating its use as a measure of elderly human capital.

Although our constructed measure is highly correlated (r = 0.90) with Barro and Lee (2013) dataset, we prefer our reconstructed measure, which is Edu_Elderly, for two econometric reasons. First, it relies on historical administrative enrollment data (Lee & Lee, 2016) rather than census surveys, thereby minimizing recall bias common among elderly populations in developing economies. Second, by estimating human capital solely from historical lags, our measure is strictly predetermined, thereby mitigating endogeneity concerns arising from contemporaneous survey measurement errors.

3.2. Data

The study collects and collates data on the key variables (description and source of the variables in Table 1) from all countries between 1990 and 2023. Among all countries, the study selects 123 countries (See Table A.1, Appendix) because they share common observations across the variables of interest. Among 123 countries, 89 are categorized as EMDEs and 34 as advance economies (AEs) by the World Bank classifications. The 5-year non-overlapping averages of all variables are used, which help filter cyclical fluctuations and improve the efficiency of the estimations (Lai & Yip, 2022). This also reflects the slow-moving nature of demographic variables, which change little at annual frequency, and is standard in the cross-country inflation literature.

Inflation is the dependent variable, measured as a change in the consumer price index. Inflation is truncated at ±25%, following Juselius and Takáts (2021) and Gajewski (2015) to minimize the bias arising from extreme inflationary and deflationary episodes.

Population aging is the key independent variable, measured as the share of the population aged 65 and above (Age65). As an alternative measure of aging, the old-age dependency ratio (OADR) is also used to check robustness. The other independent variables, such as the real interest rate (RIR), gross domestic product (GDP) growth (GDPg), the liberal democracy index (Democ), government debt (GD), and trade openness (TO), are used as control variables, motivated by the existing literature.[7] Following Juselius and Takáts (2021), the study removes observations above the 97.5th percentile and below the 2.5th percentile for all independent variables to address outliers.

[6] Refer to Table A.7, which presents an example of the construction of the elderly human capital variable.
[7] Mazumder and Diwakar (2025a), Bronistowska (2018), and Vlandas (2018).

Table 1
Description and sources of the variable used in the study.
Source: Authors compilation.

Variable	Definition	Source
InflationCPI	Annual percentage change in the consumer price index (CPI)	WDI
Age65	The population share aged 65 and above in the total population	WDI
OADR	Old-age dependency ratio: ratio of the population aged 65 and above to the working population aged 15 to 64	WDI
HCI	Human capital index: the index is based on the years of schooling and returns to education	PWT 10.1
Edu_Elderly	Refer to section 3.1 for detailed construction of this variable	Authors' estimation
LFP65	Elderly labor force participation (% of population aged 65 and above)	ILO
RIR	Real interest rate: for EMDEs, data is taken from WDI. For AEs, short-term interest rate from sources such as Jordà et al. (2017) and OECD Economic Outlook is adjusted to InflationGDP	WDI; Jordà et al. (2017); OECD Economic Outlook: Authors' estimation
GDPg	The annual change in GDP	WDI
Democ	Liberal democracy index	Coppedge et al. (2023)
GD	General government gross debt, % of GDP	Kose et al. (2022)
TO	Trade openness: export plus import (% of GDP)	WDI
BMg	Broad money growth (% of GDP)	WDI
Output_gap	Output gap: % deviation of real GDP from its HP-filtered trend	Authors' calculation using WDI

Notes: WDI denotes World Development Indicators; PWT 10.1 denotes Penn World Table 10.1; OECD refers to Organisation for Economic Co-operation and Development; EMDEs denotes emerging and developing economies; AE denotes advanced economies; ILO denotes International Labor Organization.

3.3. Methods

To assess the role of human capital in the relationship between aging and inflation, we interact population aging with the human capital index (Age65×HCI). Accordingly, the following model is constructed:

$$\begin{aligned} Inflation_{it} = {} & \beta_1 Age65_{it} + \beta_2 HCI_{it} + \beta_3\, Age65_{it} \times HCI_{it} \\ & + \beta_4 RIR_{it} + \beta_5 GDPg_{it} + C_i + T_t + C_i \times t + u_{it} \end{aligned} \tag{1}$$

Where i denotes country and t denotes 7 periods at 5-year intervals for each country, namely 1990–1994, 1995–1999, 2000–2004, 2005–2009, 2010–2014, 2015–2019, and 2020–2023. C_i and T_t denote country-fixed effects and time-fixed effects, respectively. Capturing only country and time-fixed effects may not account for changes that are specific to each country and vary over time, so following Guo et al. (2024) and Conti (2014), the study incorporates a country-specific time trend ($C_i \times t$) in the equation. As a standard practice, the study also adds two macroeconomic controls, the real interest rate and GDP growth, in the baseline equation.

We also replace HCI with the elderly human capital (Edu_Elderly), which is more relevant to the human capital associated with the aging population in the following model:

$$\begin{aligned} Inflation_{it} = {} & \beta_1 Age65_{it} + \beta_2 Edu\_Elderly_{it} + \beta_3\, Age65_{it} \times Edu\_Elderly_{it} \\ & + \beta_4 RIR_{it} + \beta_5 GDPg_{it} + C_i + T_t + C_i \times t + u_{it} \end{aligned} \tag{2}$$

In later specifications, alternative measures of aging and additional controls are also included, among others, to assess the robustness of the findings.

4. Results and discussion

4.1. Descriptive statistics

We begin by illustrating how our key variables (Human capital, Edu_Elderly, Age65, and Inflation) have changed over time for the Full sample (Fig. 3) of countries and EMDEs (Fig. 4), using five-year averages. In both samples, human capital and Edu_elderly values increased continuously from the early 1990s to the early 2020s, indicating that countries experienced improvements in overall education, including among the elderly population. The widening shaded area over time represents the 10th-90th percentile range, suggesting most countries are witnessing an improvement in education, but the pace of progress varies across countries. The share of the aging population (Age65) shows an upward trend in both samples, reflecting population aging across countries. Nevertheless, population aging is more pronounced in the full sample than in EMDEs because it includes advanced economies (e.g., Japan, the USA, the UK), many of which are super-aged. Inflation in the sample declines from the early 1990s through the mid-2000s, suggesting price stability over this period. The 10th -90th percentile range narrows from the mid-2000s onward, as inflation declines, indicating greater convergence across countries. However, the most recent period (early 2020s) witnessed a widened shaded percentile range, suggesting cross-country differences.

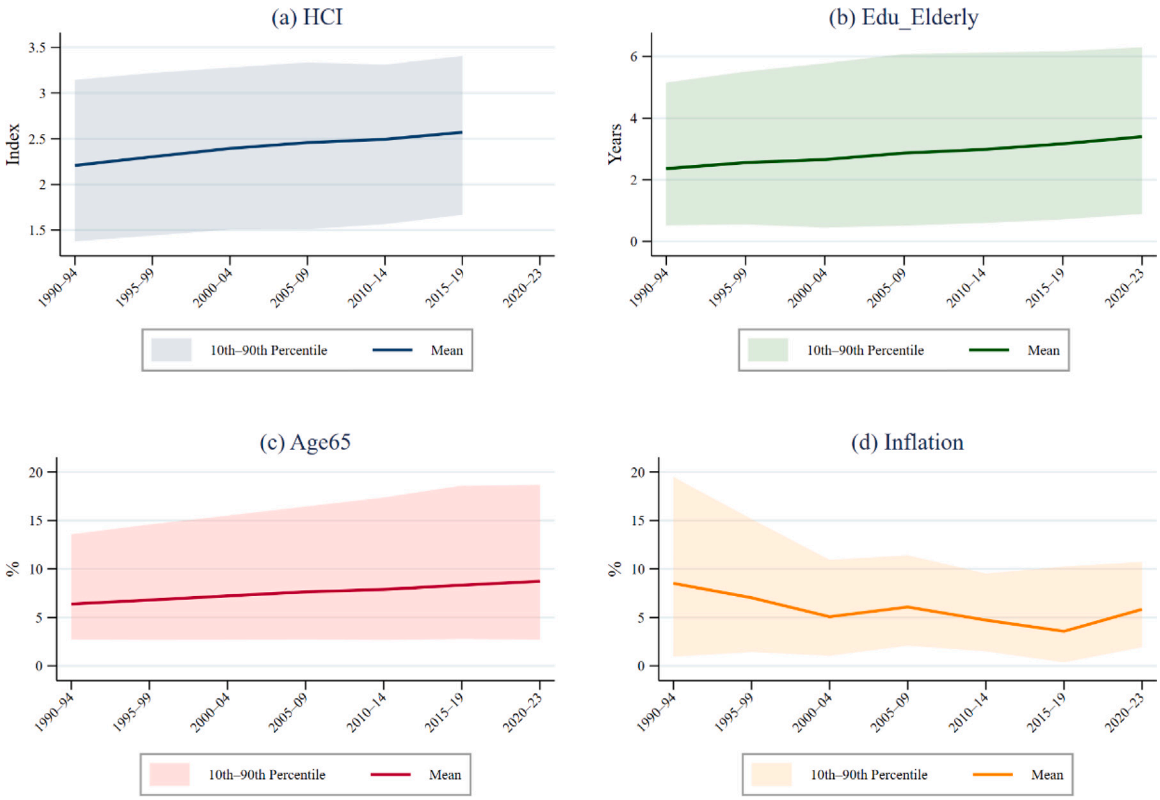


Fig. 3. Mean and 10th–90th Percentile of key variables over time (Full Sample).
Notes: The solid line denotes the sample mean, while the shaded area represents the 10th–90th percentile.
Source: Authors' illustrations.

Table 2 presents the descriptive statistics of all the variables used in the study. The panel is unbalanced because all variables have unequal sample sizes (N). The average inflation for the full sample and EMDEs is 5.71% and 6.507%, respectively, with standard deviations of 4.738% and 4.894%. These numbers indicate significant differences across countries. The average population aging (Age65) is 7.555% of the total population in the full sample, while 5.635% in EMDEs. The average human capital index (HCI) is 2.403 in the full sample and 2.18 in EMDEs. The average Elderly education (Edu_Elderly) for the full sample is 2.855 years, while 2.129 years for EMDEs. Table A.2 (Appendix) shows the correlation matrix for all variables. The higher correlation between Age65 and OADR indicates that these variables can be used alternatively in the specifications. The correlation among all explanatory variables is lower than 0.8, indicating that multicollinearity is unlikely (Gujarati, 2003).

To ensure that variables in the analysis are stationary for the full sample and EMDEs, the study initially employed the Fisher panel unit root test (Choi, 2001). However, because the Pesaran (2004, 2015) CD test decisively rejects cross-sectional independence (refer to Table A.4 in Appendix) for every variable, first-generation tests that assume cross-sectional independence are inappropriate. We therefore rely on the second-generation Pesaran (2007) cross-sectionally augmented IPS (CIPS) test, which augments the ADF regressions with cross-sectional averages to purge common factors. The CIPS results (Table A.3, Appendix) confirm that (refer to Table A.3 in Appendix) the dependent variable, Inflation, is stationary in levels, I(0), while the slow-moving demographic variables (Age65 and human capital) are highly persistent, consistent with the intuition that demographic series trend over time. Because our dependent variable is stationary, the five-year averaging substantially reduces persistence, and the specification includes country-specific trends, time effects, and Driscoll–Kraay standard errors, the level regressions deliver consistent and interpretable estimates of the long-run aging–inflation relationship.

Since the study deals with a panel of diverse countries, we apply the Pesaran (2004, 2015) cross-sectional dependence test (Table A.4, Appendix), which indicates that all variables are cross-sectionally dependent. We therefore estimate fixed-effects models with Driscoll–Kraay standard errors (Hoechle, 2007), which are robust to cross-sectional dependence, autocorrelation, and heteroskedasticity. This pooled estimator is well suited to our setting: the aging–inflation relationship is a long-run, cross-country phenomenon, and demographic variables evolve slowly within countries, so the identifying variation is primarily cross-sectional. In addition, our elderly human capital measure is built from the Barro-Lee dataset, which is available only at five-year intervals, so the annual series is a five-year average by construction and offers little year-to-year variation. Estimators that recover coefficients from within-country time variation alone therefore have limited identifying power for these variables, and mean-group-type estimators are also known to suffer small-sample bias when the time dimension is moderate (Hsiao et al., 1998; Pesaran et al., 1999). Nonetheless, to

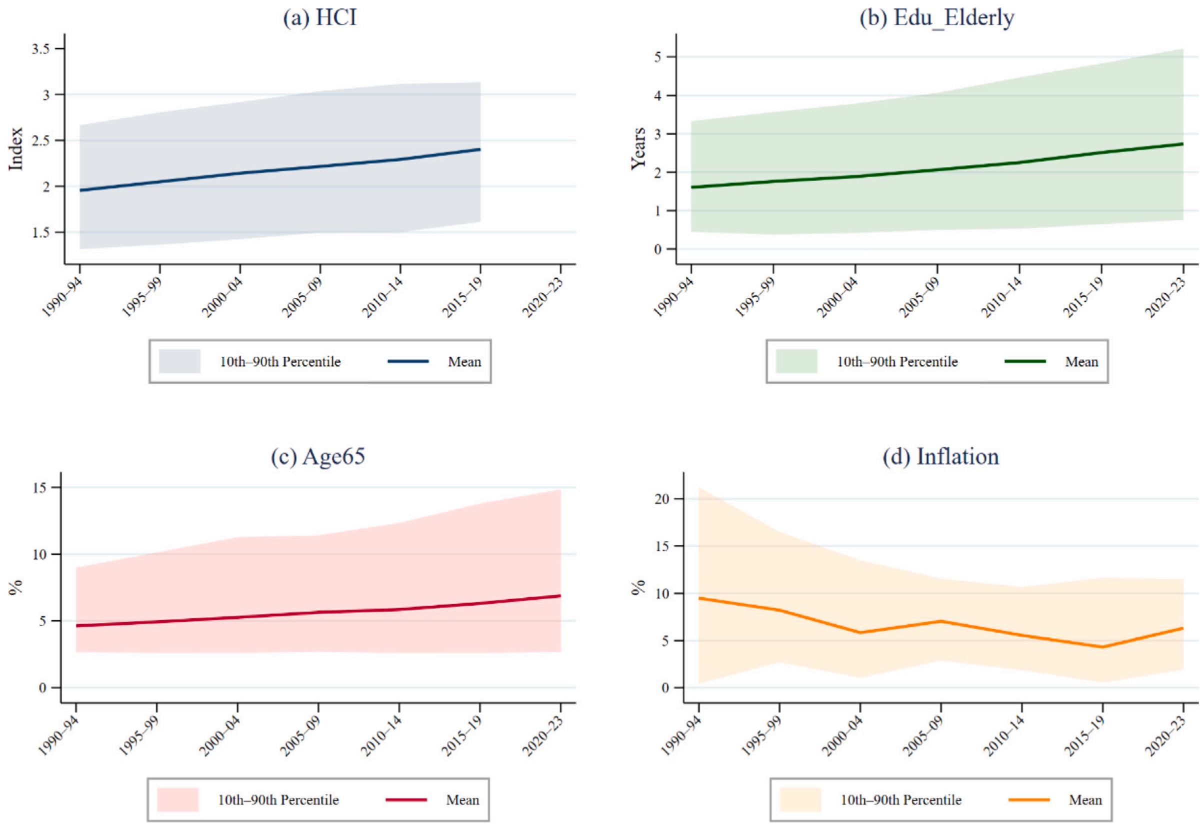


Fig. 4. Mean and 10th–90th Percentile of key variables over time (EMDEs).
Notes: The solid line denotes the sample mean, while the shaded area represents the 10th–90th percentile.
Source: Authors' illustrations.

verify that our findings are not driven by unobserved common factors, we additionally estimate the Augmented Mean Group (AMG) (Eberhardt & Bond, 2009), Common Correlated Effects Mean Group (CCEMG) (Pesaran, 2006), and Dynamic Common Correlated Effects (DCCE) (Chudik & Pesaran, 2015) estimators as a robustness check, discussed in Section 4.4 (refer to Section 4.4.3).

4.2. Empirical findings and discussion

Table 3 presents the baseline results using Driscoll–Kraay standard errors to account for cross-sectional dependence and autocorrelation. Across all specifications, our results provide strong empirical support for the hypothesis that human capital acts as a critical moderator in the relationship between population aging and inflation.

In Model 1, the coefficient for Age65 is negative and highly significant, confirming the prevailing view that population aging exerts a primary deflationary pressure. However, the interaction term Age65 × HCI is positive and significant. This suggests that while aging is deflationary in a vacuum, the intensity of this effect diminishes as the national stock of human capital increases.

Model 2 introduces our constructed variable, Edu_Elderly. Although the direct effect of Edu_Elderly is not statistically significant, the interaction term Age65 × Edu_Elderly remains positive and significant. This is an important finding because it suggests that the years of schooling of the elderly help mitigate the deflationary impact of an aging demographic. One way to look at this finding is that higher levels of education among the elderly are associated with a transition of the elderly from being purely "passive consumers" to "productive contributors" or more sophisticated consumers, thereby helping to reduce deflationary pressures.

Models 3 and 4 focus on EMDEs. We designate Model 4 as our benchmark, as it provides the most targeted analysis of how Edu_Elderly shapes the aging–inflation relationship in developing contexts. In EMDEs, the mitigating effect of human capital is even more pronounced than in the full sample. As seen in Model 3, the interaction coefficient is substantially higher than the full sample counterpart in Model 1, suggesting that human capital investments yield higher marginal benefits for price stability in younger, developing economies facing rapid demographic transitions.

The economic significance of these results is best captured by the marginal effects illustrated in Fig. 5. Fig. 5a demonstrates that the deflationary pressure of aging is conditional on the level of the Human Capital Index (HCI). At lower levels of human capital, the net effect of aging on inflation is negative. However, as HCI increases, the marginal effect of aging tends toward zero

Table 2
Descriptive statistics.
Source: Authors' estimations using World Development Indicator and Penn World Table 10.1

Variables	N	mean	sd	min	max
Full Sample					
Inflation	1024	5.710	4.733	−10.630	24.439
Age65	1092	7.555	5.226	2.009	20.181
OADR	1090	11.733	7.451	3.305	31.151
HCI	817	2.403	0.663	1.177	3.624
Edu_Elderly	584	2.855	1.963	0.270	7.360
LFP65	1099	24.577	17.699	2.118	66.723
RIR	847	4.942	5.935	−11.455	26.400
GDPg	1127	3.455	2.622	−7.523	11.685
BMg	930	16.155	10.873	−2.964	64.796
TO	1013	78.107	34.983	24.714	201.059
output_gap	1123	0.050	0.949	−5.172	5.480
Democ	1068	0.405	0.262	0.039	0.857
GD	968	54.652	30.324	7.545	194.920
EMDES					
Inflation	783	6.507	4.912	−10.63	24.44
Age65	867	5.635	3.722	2.009	19.95
OADR	867	9.007	5.186	3.305	30.42
HCI	624	2.18	0.573	1.177	3.53
Edu_Elderly	432	2.129	1.533	0.27	7.17
LFP65	869	28.5	17.57	2.161	66.72
RIR	622	6.329	6.066	−11.45	26.4
GDPg	882	3.698	2.711	−7.523	11.68
BMg	829	17.18	10.97	−2.964	64.8
TO	796	75.23	33.07	24.71	201.1
output_gap	878	0.072	0.978	−5.172	5.48
Democ	843	0.313	0.206	0.039	0.857
GD	741	52.48	29.49	7.545	154.9

Table 3
Baseline results- human capital, aging, and inflation.
Source: Authors' estimations using World Development Indicator and Penn World Table 10.1.

Model	(1)	(2)	(3)	(4)
Sample	Full Sample (1-2)		EMDEs (3-4)	
Equation	Equation (1)	Equation (2)	Equation (1)	Equation (2)
Age65	−3.817***	−1.824***	−5.282***	−2.727***
	[0.311]	[0.233]	[0.526]	[0.283]
HCI	−11.415***		−13.553***	
	[0.930]		[1.476]	
Age65 × HCI	0.999***		1.600***	
	[0.131]		[0.213]	
Edu_Elderly		−1.079		−2.633
		[1.469]		[1.736]
Age65 × Edu_Elderly		0.246***		0.499***
		[0.049]		[0.042]
RIR	−0.203***	−0.230***	−0.186***	−0.210***
	[0.028]	[0.037]	[0.036]	[0.043]
GDPg	−0.209***	−0.206***	−0.223***	−0.195***
	[0.049]	[0.046]	[0.040]	[0.039]
Observations	583	474	416	344
Number of Countries	123	88	89	64
R-squared (within)	0.760	0.740	0.760	0.753
Country-fixed	Yes	Yes	Yes	Yes
Time-fixed	Yes	Yes	Yes	Yes
Country-specific time trend	Yes	Yes	Yes	Yes

Notes: Driscoll–Kraay standard errors in brackets. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

and eventually becomes positive (inflationary) once the index reaches a threshold of approximately HCI $\approx$ 3.3[8] (95% Confidence Intervel: 3.032–3.569).

Similarly, Fig. 5b illustrates the role of years of schooling of the elderly (Edu_Elderly) in the relationship between aging and inflation. Consistent with Fig. 5a, as the education of the elderly increases, the deflationary pressure of aging reduces. When the average years of schooling for the elderly crosses $\approx$ 5.4[9] years, the marginal effect of aging becomes inflationary.

We interpret these turning points with caution, as conditional benchmarks implied by the interaction coefficients rather than structural breakpoints. Notably, only a small share of the EMDE sample lies above them, roughly 1.3% of observations for the HCI threshold and 3% for the Edu_Elderly threshold (refer to Figs. A.1–A.2, Appendix), so the deflationary effect of aging dominates across the vast majority of EMDEs, and human capital mitigates rather than universally reverses it. There is a logical consistency between the HCI threshold of 3.3 and the Edu_Elderly threshold of 5.4 years. While an HCI of 3.3 reflects an advanced, tertiary-educated general workforce (typical of high-income nations), an average of 5.4 years of schooling for the elderly represents a significant transformation for that specific cohort in EMDEs. Historically, moving from 2 years (incomplete primary) to 5 years (completed primary/early secondary) marks the transition from subsistence-based human capital to basic industrial literacy. These findings resonate with Bloom et al. (2010) and Heijdra and Reijnders (2016), indicating that longer years of schooling help economies avoid the adverse deflationary consequences of aging by fostering labor-market resilience and robust ‘‘silver’’ consumption

The control variables align with macroeconomic theory. Both real interest rate (RIR) and GDP growth (GDPg) maintain negative and significant coefficients. The negative coefficient on GDP growth merits careful interpretation. Although standard Phillips-curve reasoning links faster growth to demand-side inflationary pressure, much of the 1990–2023 growth in our EMDE sample reflects structural transformation and productivity catch-up, which is disinflationary through lower unit costs; the five-year averaging further filters out short-run, demand-driven inflation. Consistent with this, when GDP growth is replaced by the HP-filtered output gap (Table 5), the demand-side channel re-emerges, confirming that cyclical demand pressures remain inflationary even though trend growth is disinflationary in these economies.

4.3. Possible explanation: Labor market participation and education

Labor market participation among the elderly can be an effective channel for explaining how elderly human capital, i.e., Edu_Elderly, helps reduce the deflationary pressure on the population.

More years of schooling are expected to enhance the ability, willingness, and opportunities to work at older ages (Haider & Loughran, 2001). Additionally, Börsch-Supan et al. (2020) argued that higher-educated workers enter the workforce later than less educated workers. Hence, they work later in life to ensure financial stability and savings. Therefore, the highly educated labor force will positively contribute to the economy and even help reduce the deflationary pressure from aging.

To prove this empirically, we introduce the interaction of aging and elderly labor force participation (Age65 $\times$ LFP65) in Eq. (2) for EMDEs and find the interaction positive and statistically significant, which proves the point that higher elderly labor force participation weakens the deflationary pressure of aging (model 1, Table A.6, Appendix).

However, we argue that participation alone is insufficient; the quality of that participation matters. To demonstrate this, we split the sample into two groups based on the elderly's median education (Edu_Elderly).[10] After running the regression with less educated elderly regions (Model 2, Table A.6, Appendix), the interaction (Aging $\times$ LFP65) coefficient remains statistically irrelevant. However, in regions with higher levels of elderly education, the interaction (Aging $\times$ LFP65) coefficient is positive and statistically significant, indicating that only a highly skilled senior workforce can effectively moderate the deflationary impact of demographic shifts.

We demonstrate this distinction in Fig. 6. While Fig. 6a shows that older labor force participation generally weakens deflationary pressure, Fig. 6b confirms that this reduction is statistically significant and economically meaningful only when the elderly labor force is more educated, suggesting that human capital is the ‘‘precondition’’ that allows labor participation to act as an inflationary buffer.

4.4. Robustness checks

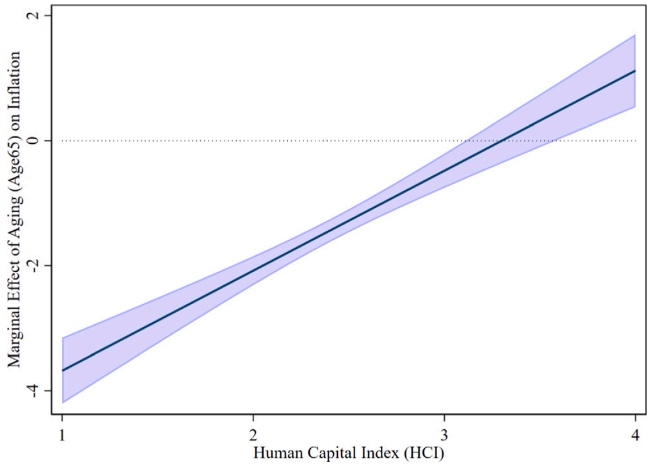
4.4.1. Splitting the EMDEs sample

To assess the consistency of our findings across EMDEs, we split the EMDE sample into low-income EMDEs and high-income EMDEs based on the median log GDP per capita. We present the results in Table 4. The findings reveal that the coefficient of our key interaction term (Age65 $\times$ Edu_Elderly) is positive and statistically significant only in the high-income EMDEs regions, consistent with the baseline results. By contrast, the interaction term is statistically insignificant for low-income EMDEs. This pattern is plausible for two reasons. The results for low-income EMDE regions, though statistically significant, seem counterintuitive. However, there could be two reasons for statistically insignificant results for low-income EMDEs. First, low-income EMDEs tend to have a lower share of the elderly population. In other words, the pace of aging in low-income EMDEs is lower (Mazumder & Diwakar, 2026), resulting

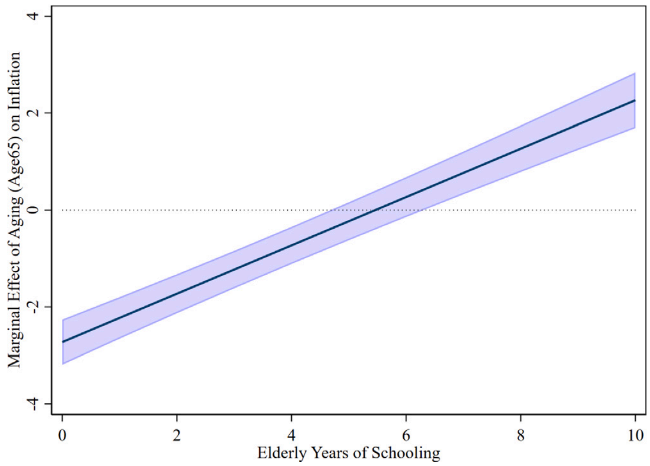
[8] We have estimated critical threshold for HCI in the following manner: $\frac{\partial \text{Inflation}it}{\partial \text{Age65}it} = \beta_1 + \beta_3 \text{HCI}_{it} = 0, \Rightarrow \text{HCI} = -\frac{-5.282}{1.600} \approx 3.3$. The confidence intervals are estimated using the Delta method in Stata 17.

[9] We have estimated the critical threshold for Edu_Elderly in the following manner: $\frac{\partial \text{Inflation}_{it}}{\partial \text{Age65}_{it}} = \beta_1 + \beta_3 \text{Edu\_Elderly}_{it} = 0 \Rightarrow \text{Edu\_Elderly} = -\frac{-2.727}{0.499} \approx 5.4$. The confidence intervals are estimated using the Delta method in Stata 17.

[10] Refer to Table A.6 (Appendix) to see the countries in less educated elderly and more educated elderly regions.



(a)



(b)

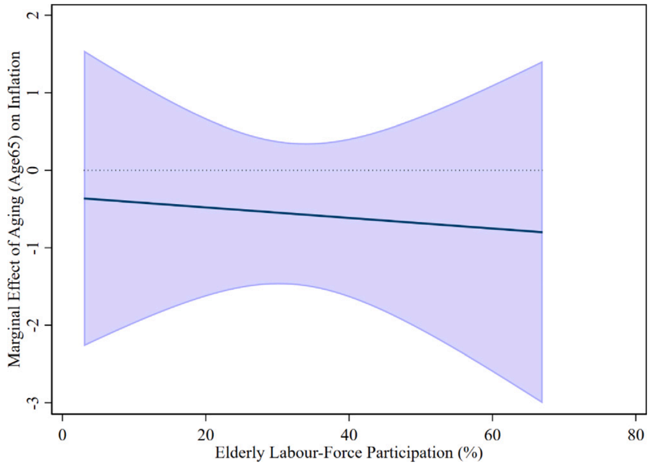
Fig. 5. Marginal effect of aging on inflation at various levels of Human capital. For Fig. 5a: Source- Authors' illustrations by estimation of marginal effects $\left(\frac{\partial \text{Inflation}it}{\partial \text{Age65}it} = \beta_1 + \beta_3 \text{HCI}_{it}\right)$ from Model 3 (Table 3). For Fig. 5b: Source- Authors' illustrations by estimation of marginal effects $\frac{\partial \text{Inflation}_{it}}{\partial \text{Age65}_{it}} = \beta_1 + \beta_3 \text{Edu\_Elderly}_{it}$ from Model 4 (Table 3).

in statistically insignificant differences. Second, low-income EMDEs also have a critically low level of elderly human capital. For instance, the average years of schooling of the elderly in low-income EMDEs regions are 1.94, compared to 2.24 in high-income EMDEs regions, well below the estimated turning point, so few, if any, low-income observations reach the range in which human capital begins to offset the deflationary effect of aging.

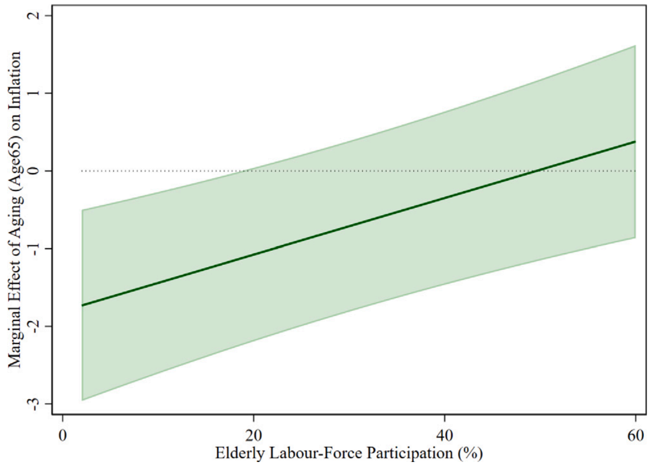
This exercise of splitting EMDEs samples highlights that the role of income level within EMDEs is an important conditioning factor for the relationship between aging and inflation and the role of elderly human capital. Substantively, the mitigating role of elderly human capital operates where the demographic transition is already underway and where the elderly have accumulated enough schooling to cross into the mitigating range; in the poorest economies, both preconditions are largely absent.

4.4.2. Alternative measure of aging and additional controls

To verify the validity of our baseline findings, we conduct several robustness tests using alternative variable specifications and additional macroeconomic controls. The results are in Table 5. In Model 1, we replace our primary aging variable (Age65) with the Old-Age Dependency Ratio (OADR) to account for the structural burden on the working-age population. The results are highly consistent with our benchmark findings: the OADR exerts a strong deflationary pressure, but the interaction term (OADR × Edu_Elderly) is positive and significant, confirming that the moderating role of elderly human capital is not sensitive to the specific demographic proxy used.



(a)



(b)

Fig. 6. Marginal effect of Aging on inflation depending on the education of the elderly. For Fig. 6a: Less-educated elderly; Source- Authors' illustrations by estimation of marginal effects $\frac{\partial \text{Inflation}_{it}}{\partial \text{Age65}_{it}} = \beta_1 + \beta_3 \text{LFP}_{it}$ from Model 2 (Table A.5, Appendix). For Fig. 6b: More-educated elderly; Source: Authors' illustrations by estimation marginal effects $\frac{\partial \text{Inflation}_{it}}{\partial \text{Age65}_{it}} = \beta_1 + \beta_3 \text{LFP}_{it}$ from Model 3 (Table A.5, Appendix).

As a further robustness test, we progressively add controls capturing macroeconomic and institutional conditions: trade openness (TO), broad-money growth (BMg), the output gap, government debt (GD), and the liberal democracy index (Democ) (Models 2–6). The coefficient on trade openness is positive and highly significant (Models 2–6), consistent with Mazumder and Diwakar (2025a), suggesting that EMDEs that are more integrated into the global economy may experience inflationary pressures driven by international price pass-through and increased domestic demand. Broad-money growth also enters positively and significantly, as expected from the monetary determinants of inflation. The coefficient on the output gap is not statistically significant, and that on government debt is only marginally significant (Models 5–6). Finally, the liberal democracy index is negative and significant (Model 6), suggesting that EMDEs with stronger democratic institutions tend to maintain lower inflation.

We also probe the sensitivity of our findings to the choice of monetary and demand controls and to the pandemic period. In Model 7, replacing the real interest rate with broad-money growth leaves the interaction unchanged (0.408). In Model 8, replacing GDP growth with the output gap yields a similar result (0.519). In Model 9, we exclude the COVID-19 period (2020–2023); the interaction remains positive and significant (0.394), confirming that the extraordinary pandemic inflation does not drive our conclusions.

Across all nine specifications, the interaction between Age65 (or OADR) and Edu_Elderly remains positive and statistically significant, with the implied turning point stable in the range of roughly 4.8 to 5.7 years of elderly schooling. This consistency confirms the moderating role of elderly human capital (Edu_Elderly) in shaping the nexus between aging and inflation.

Table 4
Sample splits: EMDEs regions based on income level.
Source: Authors' estimations using World Development Indicator and Penn World Table 10.1.

Models Variables	(1) High-Income EMDEs regions	(2) Low-Income EMDEs regions
Edu_Elderly	−7.319**	5.305
	[2.418]	[5.528]
Age65	−4.149***	−0.463
	[0.584]	[0.948]
Age65 × Edu_Elderly	0.994***	−0.059
	[0.116]	[0.137]
RIR	−0.192***	−0.277***
	[0.033]	[0.063]
GDPg	−0.202**	−0.152
	[0.082]	[0.110]
Observations	218	125
Number of Countries	37	27
R-squared (within)	0.802	0.695
Country-fixed	Yes	Yes
Time-fixed	Yes	Yes
Country-specific time trend	Yes	Yes

Notes: Driscoll–Kraay standard errors in brackets. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 5
Alternative measure, additional controls, COVID Period (EMDEs).
Source: Authors' estimations using World Development Indicator, Penn World Table 10.1, Coppedge et al. (2023), and Kose et al. (2022).

Models Variables	(1) OADR	(2) +TO	(3) +BMg	(4) +OutputGap	(5) +GD	(6) +Democ	(7) BMg-for-RIR	(8) OutputGap-for-GDPg	(9) Pre-COVID
Edu_Elderly	−2.461	−4.995*	−7.724***	−7.735***	−14.633***	−11.719***	−4.468**	−2.906*	−4.061
	[1.579]	[2.162]	[1.464]	[1.426]	[1.230]	[1.378]	[1.462]	[1.346]	[2.295]
Age65		−3.382***	−2.819***	−2.823***	−3.894***	−3.579***	−2.305**	−2.962***	−2.775***
		[0.248]	[0.544]	[0.517]	[0.750]	[0.634]	[0.656]	[0.382]	[0.412]
Age65 × Edu_Elderly		0.660***	0.592***	0.593***	0.808***	0.721***	0.408***	0.519***	0.394**
		[0.062]	[0.077]	[0.071]	[0.112]	[0.080]	[0.081]	[0.067]	[0.106]
GDPg	−0.204***	−0.196**	−0.322***	−0.320***	−0.227***	−0.297***	−0.270***		−0.218**
	[0.037]	[0.065]	[0.063]	[0.046]	[0.057]	[0.066]	[0.053]		[0.059]
RIR	−0.204***	−0.232***	−0.172***	−0.172***	−0.157	−0.162*		−0.196***	−0.191**
	[0.049]	[0.061]	[0.046]	[0.046]	[0.083]	[0.075]		[0.043]	[0.051]
TO		0.070**	0.044**	0.044**	0.048***	0.049***			
		[0.024]	[0.014]	[0.015]	[0.012]	[0.013]			
	[0.511]	[0.605]	[0.464]	[0.491]	[0.559]	[0.743]	[0.466]	[0.469]	[1.006]
	[1.015]	[1.083]	[1.197]	[1.174]	[1.169]	[0.906]	[1.248]	[1.052]	[1.496]
OADR	−1.374***								
	[0.192]								
	0.291***								
	[0.029]								
BMg			0.198***	0.197***	0.174**	0.180**	0.185***		
			[0.036]	[0.036]	[0.054]	[0.054]	[0.027]		
output_gap				−0.017	0.025	0.099		−0.334	
				[0.246]	[0.187]	[0.209]		[0.331]	
GD					0.022	0.026*			
					[0.011]	[0.013]			
Democ						−6.125**			
						[2.028]			
Observations	346	310	305	304	273	267	375	343	300
Number of Countries	64	60	60	59	59	58	64	63	64
R-squared (within)	0.757	0.790	0.833	0.833	0.788	0.798	0.766	0.752	0.794
Country-fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-specific time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Driscoll–Kraay standard errors in brackets. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. + symbol indicate variables that are added in the benchmark model (Model 4, Table 3).

Table 6
Dynamic panel estimates: Dynamic Driscoll–Kraay and System GMM.
Source: Authors' estimations using World Development Indicators and Penn World Table 10.1.

Variables	(1) Dynamic-DKFE	(2) System-GMM
L.Inflation	0.013	0.465***
	[0.081]	(0.100)
Age65	−1.097	−0.359**
	[0.706]	(0.162)
Edu_Elderly	−2.731	−1.029***
	[2.124]	(0.332)
Age65 × Edu_Elderly	0.259**	0.092**
	[0.078]	(0.039)
GDPg	−0.115*	−0.180**
	[0.046]	(0.088)
RIR	−0.184*	−0.044
	[0.074]	(0.052)
Observations	298	298
Number of Countries	62	62
AR2 p-value		0.268
Hansen p-value		0.490
Instruments		61
R-squared (within)	0.646	
Country-fixed	Yes	Yes
Time-fixed	Yes	Yes
Country-specific time trend	Yes	

Notes: Column (1) is a dynamic Driscoll–Kraay fixed-effects model; column (2) is a two-step System GMM (Arellano & Bover, 1995; Blundell & Bond, 1998). In the System-GMM specification, GMM-style instruments use lags (2 3) of lagged inflation, Age65, Edu_Elderly, and the Age65 × Edu_Elderly interaction, while GDP growth, the real interest rate, and year dummies enter as exogenous (standard) instruments; robust standard errors apply the Windmeijer (2005) finite-sample correction. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.4.3. Alternative estimation method: Dynamic models

We have estimated our key results using the Driscoll–Kraay model up to this section. In this section, we consider two dynamic specifications (Table 6) to address inflation persistence and potential endogeneity of the aging variables: a dynamic Driscoll–Kraay model that adds the lagged dependent variable, and the System Generalized Method of Moments (GMM), developed by Arellano and Bover (1995) and Blundell and Bond (1998), as a robustness check. Previous studies, including Mazumder and Diwakar (2026) and Juselius and Takáts (2021), also used System-GMM for robustness and to account for endogenous persistence. The system GMM regression equation can be found in Eq. (3).

$$\begin{aligned} Inflation_{it} &= \rho\, Inflation_{i,t-1} + \beta_1 Age65_{it} + \beta_2 HCI_{it} + \beta_3\, Age65_{it} \times HCI_{it} \\ &\quad + \beta_4 RIR_{it} + \beta_5 GDPg_{it} + C_i + T_t + u_{it} \end{aligned} \tag{3}$$

The Eq. (3) differs the baseline static models (Eqs. (1) & (2)) by including the lagged dependent variable (to capture inflation persistence. The interaction term of interest (Age65 × Edu_Elderly) remains positive and significant in both specifications (0.259 in the dynamic Driscoll–Kraay model and 0.092 in System GMM, both at the 5% level), mirroring the baseline in Table 3.

The two models also clarify persistence. In the dynamic Driscoll–Kraay model the lagged inflation coefficient is near zero and insignificant (0.013), indicating that five-year averaging removes most high-frequency persistence and justifying the static baseline. Because the within transformation biases this coefficient downward in short panels (Nickell, 1981), System GMM corrects it through internal instruments, where lagged inflation rises to 0.465 and confirms moderate persistence in EMDEs (Ha et al., 2019).

The System-GMM diagnostics support the specification (Roodman, 2009): the Arellano-Bond test rejects AR(1) (p = 0.011) but not AR(2) (p = 0.268), the Hansen J test does not reject instrument validity (p = 0.490), and the instrument count (61) is kept below the number of countries (62). In ntshel, the interaction term is stable across the static and both dynamic estimators, providing robust evidence that elderly human capital is associated with weaker deflationary pressures from population aging.

Finally, to ensure our results are not driven by unobserved common factors, we estimate the Augmented Mean Group (AMG; Eberhardt & Bond, 2009), Common Correlated Effects Mean Group (CCEMG; Pesaran, 2006), and Dynamic Common Correlated Effects (DCCE; Chudik & Pesaran, 2015) estimators. These estimators confirm that our macroeconomic controls are robust, the real interest rate remains negative and significant throughout, and the DCCE cross-sectional dependence statistic is insignificant (CD = −1.26, p = 0.21), indicating that common factors are well absorbed. However, because these estimators identify coefficients solely from within-country time variation, they cannot separately identify our slow-moving, highly persistent demographic variables, which

Table 7
Survivorship robustness: elderly schooling by age band (EMDEs).
Source: Authors' estimations using World Development Indicator and Barro and Lee (2013) dataset.

Models Variables	(1) BL_edu6569	(2) BL_edu7074	(3) BL_edu75
Age65	−1.436*** [0.277]	−0.640*** [0.114]	−0.779* [0.286]
BL_edu6569	−0.088 [0.331]		
Age65 × BL_edu6569	0.108** [0.028]		
BL_edu_7074		−0.071 [0.205]	
Age65 × BL_edu7074		0.077 [0.061]	
BL_edu75			−0.278 [0.500]
Age65 × BL_edu75			0.058 [0.081]
GDPg	−0.196*** [0.024]	−0.194*** [0.020]	−0.279*** [0.034]
RIR	−0.144*** [0.014]	−0.168*** [0.013]	−0.160*** [0.015]
Observations	311	309	304
Number of Countries	81	81	82
R-squared (within)	0.787	0.789	0.786
Country-fixed	Yes	Yes	Yes
Time-fixed	Yes	Yes	Yes
Country-specific time trend	Yes	Yes	Yes

Notes: Driscoll–Kraay standard errors in brackets. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

take implausibly large values owing to within-country collinearity. This reflects the data rather than the underlying relationship: age shares are highly persistent, and elderly human capital, being constructed from the five-yearly Barro–Lee data, is effectively constant within each five-year window even in annual specifications, leaving these estimators little variation to work with. We therefore retain the pooled Driscoll–Kraay estimator, which exploits the cross-country variation that identifies the aging–inflation relationship, as our primary specification.[11]

4.4.4. *Survivorship robustness of the elderly human-capital measure*

A potential concern with our measure of elderly human capital is survivorship bias. Because more educated individuals tend to live longer, the elderly who survive to old age may be disproportionately well educated, so that our schooling measure partly reflects who survived rather than the true educational attainment of that generation. To examine this, we use schooling data for three separate elderly age groups, those aged 65–69 (BL_edu6569), 70–74 (BL_edu7074), and 75 and above (BL_edu75) (refer to Table 7), sourced from Barro and Lee (2013). The logic is straightforward: survivorship bias becomes more severe with age, because more members of a generation have died by age 75 than by age 69. The 65–69 group is therefore the least affected by survivorship, while the 75-and-above group is the most affected.

Two findings indicate that survivorship bias does not explain our results. First, average years of schooling fall with age, 3.53 years for the 65–69 group, 3.31 for the 70–74 group, and 3.13 for the 75-and-above group. If survivorship bias were strong, the oldest group would appear the most educated, since only the more educated would have survived. The opposite pattern holds, which indicates that these differences reflect genuine generational (cohort) effects, older individuals were schooled in earlier decades when education was less widespread, rather than selective survival.

5. Conclusion and policy implications

The study examines the nexus between aging and inflation across a broad sample of 123 countries, with a specific focus on 89 EMDEs. It presents a novel finding: higher human capital is associated with weaker the deflationary pressures of aging from aging and, for a small number of high-human-capital economies, with an inflationary effect. Since the human capital index captures a broad measure of knowledge and skills in the economy, we construct a more targeted measure of human capital related to the elderly: the years of schooling of the elderly. By using this measure in our model, we find that more years of schooling among the elderly are

[11] The full AMG, CCEMG, and DCCE results are available from the authors upon request.

associated with weaker deflationary pressure from population aging. The empirical findings on elderly human capital complement those from the human capital index, highlighting the role of human capital as a fundamental structural feature in shaping the relationship between aging and inflation. While our identification strategy, including the dynamic System-GMM specification and the consistency of results across estimators, mitigates endogeneity concerns, we interpret these findings as robust conditional associations rather than definitive causal effects.

The study conducted a battery of tests to ensure the robustness of the findings. The tests include splitting the sample within EMDEs, alternative measures of aging, and key additional controls such as government debt, trade openness, broad-money growth, the output gap, and liberal democracy index. Moreover, an alternative estimator, the system GMM, is also employed. We further verify that our results are not driven by unobserved common factors or by survivorship bias in the elderly human-capital measure. The key finding that higher human capital is associated with deflationary pressure remains consistent across specifications. To explain the possible channel through which elderly human capital is associated with weaker deflationary pressure of aging, we use two regions, one with a less educated elderly labor force participation and another with more educated elderly labor force participation, and the findings reveal that the moderating association is concentrated among the more educated elderly, consistent with their contributing positively to the economy.

Our findings highlight the importance of investing in education to navigate the challenges posed by population aging. To address this, policymakers need to focus on lifelong learning programs by expanding access to education, particularly for older adults who are uneducated and for the general population. Reducing this “education gap” is essential for transitioning dependent elderly consumers to active economic contributors, a point reinforced by Long et al. (2024), who show that educational investment partially offsets the negative effects of aging on household financial stability. Additionally, the government should encourage labor force participation among older people by introducing different incentive programs. For instance, employer incentives include tax benefits and wage subsidies. Flexible retirement and options for re-skilling training programs can also ensure elderly labor force participation. Nevertheless, policies need to prioritize healthcare support to ensure healthy elderly labor force participation. Overall, these policies will reduce the burden on the pension and welfare security system, making the economy more resilient amid population aging.

6. Limitations of the study

Despite the novel contributions, the present study is subject to a few limitations. First, the construction of the elderly human capital variable (Edu_Elderly) depends on historical backward mapping, which inherently assumes that the education of survivors accurately reflects that of their original birth cohort. However, it is well-established that people with more education have higher life expectancy (Hoque et al., 2019), which may introduce survivorship bias and, consequently, lead to a higher measured stock of elderly human capital. We directly address this concern in Section 4.4 (refer to Section 4.4.4) using age-band-specific schooling data and find that our results are not an artifact of selective survival; nonetheless, we acknowledge it as a data limitation. Second, the study uses the Lee and Lee (2016) dataset for long-run education attainment. However, historical data for EMDEs in the early 20th century often rely on reconstruction and interpolation, which may introduce measurement error into the estimates. Lastly, our measurement of elderly human capital relies exclusively on the quantity of education (such as years of schooling) rather than its quality. Additionally, educational standards across countries may differ significantly. Nevertheless, these limitations remain a promising avenue for future research on the human capital and aging–inflation nexus.

CRediT authorship contribution statement

Jakir Hussain Mazumder: Formal analysis, Software, Writing – original draft. **Bharat Diwakar:** Conceptualization, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

See Figs. A.1 and A.2 and Tables A.1–A.7.

Data availability

Data will be made available on request.

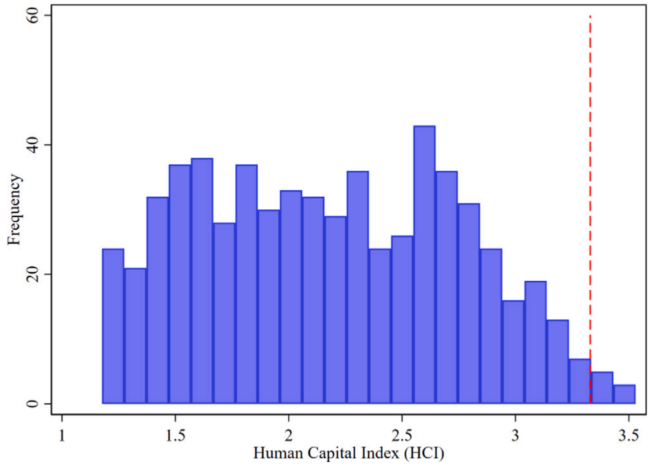


Fig. A.1. Distribution of HCI across EMDEs. Notes: Only 1.3% of the observations lie above the turning points of 3.3. *Source:* Authors' illustrations.

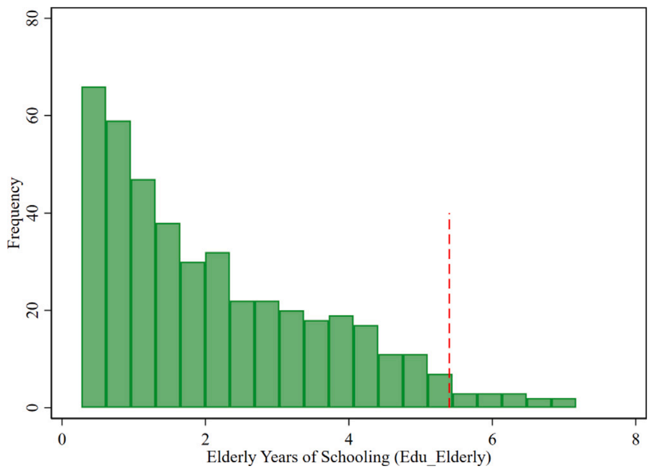


Fig. A.2. Distribution of elderly schooling across EMDEs. Notes: Only 3% of the observations lie above the turning points of 5.4 years. *Source:* Authors' illustrations.

Table A.1
List of countries used in the analysis.
Source: Authors' compilations.

Full Sample (123)	Albania, Algeria, Angola, Armenia, Australia, Austria, Bahrain, Bangladesh, Barbados, Belgium, Belize, Benin, Bolivia, Botswana, Brazil, Brunei Darussalam, Bulgaria, Burkina Faso, Burundi, Canada, Chile, China, Colombia, Congo, Dem. Rep., Costa Rica, Cote d'Ivoire, Croatia, Czechia, Denmark, Dominican Republic, Egypt, Arab Rep., Estonia, Eswatini, Ethiopia, Fiji, Finland, France, Gambia, The, Germany, Greece, Guatemala, Guyana, Haiti, Honduras, Hungary, Iceland, India, Indonesia, Iran, Islamic Rep., Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Korea, Rep., Kuwait, Kyrgyz Republic, Lao PDR, Latvia, Lesotho, Liberia, Lithuania, Luxembourg, Madagascar, Malawi, Malaysia, Maldives, Mali, Malta, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Mozambique, Myanmar, Namibia, Netherlands, New Zealand, Nicaragua, Niger, Nigeria, Norway, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russian Federation, Rwanda, Senegal, Serbia, Sierra Leone, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Tajikistan, Tanzania, Thailand, Togo, Trinidad and Tobago, Turkiye, Uganda, Ukraine, United Kingdom, United States, Uruguay, Venezuela, RB, Viet Nam, Yemen, Rep., Zambia, and Zimbabwe
EMDEs (89)	Albania, Algeria, Angola, Armenia, Bahrain, Bangladesh, Barbados, Belize, Benin, Bolivia, Botswana, Brazil, Brunei Darussalam, Bulgaria, Burkina Faso, Burundi, Chile, China, Colombia, Congo, Dem. Rep., Costa Rica, Cote d'Ivoire, Dominican Republic, Egypt, Arab Rep., Eswatini, Ethiopia, Fiji, Gambia, The, Guatemala, Guyana, Haiti, Honduras, Hungary, India, Indonesia, Iran, Islamic Rep., Iraq, Jamaica, Jordan, Kenya, Kuwait, Kyrgyz Republic, Lao PDR, Lesotho, Liberia, Madagascar, Malawi, Malaysia, Maldives, Mali, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Mozambique, Myanmar, Namibia, Nicaragua, Niger, Nigeria, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Romania, Russian Federation, Rwanda, Senegal, Serbia, Sierra Leone, South Africa, Sri Lanka, Tajikistan, Tanzania, Thailand, Togo, Trinidad and Tobago, Turkiye, Uganda, Ukraine, Uruguay, Venezuela, RB, Viet Nam, Yemen, Rep., Zambia, and Zimbabwe

Table A.2
Correlation matrix.
Source: Authors' estimations using World Development Indicator, Penn World Table 10.1, Coppedge et al. (2023), and Kose et al. (2022).

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Full Sample													
(1) Inflation	1.000												
(2) Age65	−0.156	1.000											
(3) OADR	−0.147	0.996	1.000										
(4) HCI	−0.235	0.790	0.766	1.000									
(5) Edu_Elderly	−0.217	0.798	0.794	0.849	1.000								
(6) LFP65Both	0.113	−0.662	−0.642	−0.631	−0.571	1.000							
(7) RIRn	0.153	−0.324	−0.296	−0.289	−0.230	0.311	1.000						
(8) GDPg	−0.014	−0.218	−0.227	−0.187	−0.323	0.166	−0.015	1.000					
(9) Democ	−0.141	0.577	0.584	0.546	0.745	−0.341	−0.055	−0.237	1.000				
(10) ggdy	0.110	−0.013	−0.003	0.015	0.034	−0.112	0.122	−0.203	0.035	1.000			
(11) TO	−0.170	0.046	0.032	0.204	0.178	−0.145	−0.009	−0.110	−0.037	0.191	1.000		
(12) output_gap	−0.112	0.043	0.032	0.094	0.080	0.022	−0.053	0.067	0.013	−0.062	−0.027	1.000	
(13) BMg	0.668	−0.211	−0.202	−0.305	−0.330	0.211	0.145	0.321	−0.282	−0.068	−0.165	−0.053	1.000
EMDEs													
(1) Inflation	1.000												
(2) Age65	−0.049	1.000											
(3) OADR	−0.038	0.996	1.000										
(4) HCI	−0.125	0.736	0.709	1.000									
(5) Edu_Elderly	−0.079	0.745	0.738	0.790	1.000								
(6) LFP65Both	0.043	−0.621	−0.596	−0.592	−0.501	1.000							
(7) RIRn	0.112	−0.269	−0.239	−0.220	−0.141	0.282	1.000						
(8) GDPg	−0.051	−0.151	−0.157	−0.138	−0.300	0.116	−0.054	1.000					
(9) Democ	−0.022	0.440	0.451	0.355	0.637	−0.223	0.057	−0.197	1.000				
(10) ggdy	0.118	−0.007	0.003	0.071	0.072	−0.150	0.132	−0.191	0.077	1.000			
(11) TO	−0.199	0.086	0.074	0.304	0.314	−0.192	−0.011	−0.126	0.003	0.183	1.000		
(12) output_gap	−0.130	0.056	0.046	0.114	0.119	0.020	−0.062	0.054	0.014	−0.028	−0.035	1.000	
(13) BMg	0.661	−0.118	−0.103	−0.230	−0.247	0.154	0.108	0.298	−0.207	−0.066	−0.187	−0.083	1.000

Table A.3
Second-generation panel unit-root test (Pesaran 2007 CIPS), EMDEs.
Source: Authors' estimations.

Variable	CIPS (level)	CIPS (1st diff.)	Order
Inflation	−3.224***	−4.875***	I(0)
Age65	−2.181	−2.148	I(1)
OADR	−2.556**	−2.413**	I(0)
HCI	−1.763	−1.250	I(1)
GDPg	−3.232***	−5.275***	I(0)
RIR	−2.829***	−4.468***	I(0)
TO	−2.034	−4.094***	I(1)
BMg	−3.334***	−5.206***	I(0)
Output gap	−4.677***	−5.656***	I(0)

Notes: Annual data. H_0: unit root (series is I(1)). Critical values (intercept case): 1% = −2.40, 5% = −2.22, 10% = −2.14. ***, **, * denote rejection of the unit-root null at the 1%, 5%, and 10% levels, respectively. Inflation is stationary in levels, whereas the slow-moving demographic variables are highly persistent. Edu_Elderly is available only at five-year intervals, not annually, and is therefore excluded from the CIPS test.

Table A.4
Cross-sectional independence test (Pesaran, 2004, 2015).
Source: Authors' estimations using World Development Indicator, Penn World Table 10.1, Coppedge et al. (2023), and Kose et al. (2022).

	Inflation	Age65	OADR	HCI	Edu_Elderly	LFP65	RIR	GDPg	Democ	GD	TO	BMg	Output_gap
Full Sample													
CD-test value	74.766	123.038	75.763	210.224	152.260	17.565	47.134	24.978	40.954	61.062	33.599	62.629	70.610
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
EMDEs													
CD-test value	49.547	76.676	41.198	159.308	112.919	45.929	27.568	24.645	28.332	65.989	18.691	60.707	42.326
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: Null hypothesis: Cross-sectional independence. We reject the null hypothesis of cross-section independence if the p-value is less than 0.05.

Table A.5
Possible explanations: Elderly labor force participation channel (EMDEs).
Source: Authors' estimations using World Development Indicator, ILO, and Penn World Table 10.1.

Model Sample	(1) Full sample	(2) Less educated elderly region	(3) More educated elderly region
Edu_Elderly	−3.007		
	[1.591]		
Age65	−4.232***	−0.342	−1.804*
	[0.703]	[1.254]	[0.759]
RIR	−0.254***	−0.248**	−0.197**
	[0.038]	[0.080]	[0.062]
GDPg	−0.197***	−0.543***	−0.184*
	[0.047]	[0.133]	[0.089]
Age65 × Edu_Elderly	0.590***		
	[0.063]		
Age65 × LFP65	0.027*	−0.007	0.036**
	[0.014]	[0.035]	[0.012]
LFP65	−0.158*	0.080	−0.101
	[0.069]	[0.308]	[0.137]
Observations	334	141	196
Number of countries	63	31	32
R-squared (within)	0.774	0.685	0.787
Country-fixed	Yes	Yes	Yes
Time-fixed	Yes	Yes	Yes
Country-specific time trend	Yes	Yes	Yes

Notes: Driscoll–Kraay standard errors in brackets. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A.6
List of countries with more and less elderly education.
Source: Authors' compilation.

Regions	Countries
More educated elderly region	Albania, Barbados, Belize, Bolivia, Brazil, Bulgaria, Chile, Colombia, Costa Rica, Dominican Republic, Fiji, Guyana, Honduras, Hungary, Jamaica, Lesotho, Malaysia, Mauritius, Mexico, Nicaragua, Panama, Paraguay, Peru, Philippines, Poland, Romania, Russian Federation, Serbia, South Africa, Sri Lanka, Trinidad and Tobago, and Uruguay
Less educated elderly region	Algeria, Bangladesh, Benin, China, Congo, Dem. Rep., Cote d'Ivoire, Egypt, Arab Rep., Gambia, The, Guatemala, Haiti, India, Indonesia, Iran, Islamic Rep., Iraq, Jordan, Kenya, Kuwait, Liberia, Malawi, Mali, Mozambique, Myanmar, Niger, Pakistan, Senegal, Sierra Leone, Thailand, Togo, Turkiye, Uganda, Venezuela, RB, Zambia, and Zimbabwe

Notes: The regions are divided based on the median value (1.565) of education of the elderly (Edu_Elderly).

Table A.7
Backward-Mapping Estimation of Elderly Human Capital (Example: Year (t)= 1995).
Source: Author's construction.

	Current Age (Age_t)	Birth Year ($t - Age_t$)	Historical Reference Year for schooling data for aged 15 and above (15+)($t - k$)	Time lag (k)	Historical Schooling data (S_{t-k})	Aggregation logic
	100	1895	1910	85	1.5 years	Start of Smoothing Window
	65	1930	1945	50	4.5 years	End of Smoothing Window
Variable Construction	65–100	1895–1930	1910–1945	50–85	3 years	$= \frac{1}{36}\sum_{k=50}^{85} S_{i,t-k}$

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