GDP per capita and human capital investment in five countries after exhaustion of the first demographic dividend

Éva Berde
(corresponding author)
Kautz Gyula Faculty of Business and Economics, Department of International and Applied Economics,
Széchenyi István University
Győr, Hungary
Email: berde.eva@sze.hu

Izabella Kuncz
Institute of Economics
Corvinus University of Budapest,
Budapest, Hungary
Email: izabella.kuncz@uni-corvinus.hu

Petra Németh
Institute of Economics
Corvinus University of Budapest,
Budapest, Hungary
Email: petra.nemeth@uni-corvinus.hu

Sándor Remsei
Kautz Gyula Faculty of Business and Economics, Department of International and Applied Economics,
Széchenyi István University,
Győr, Hungary
Email: remsei.sandor@sze.hu

Eszter Szabó-Bakos
Institute of Economics
Corvinus University of Budapest,
Budapest, Hungary
Email: eszter.szabobakos@uni-corvinus.hu

Keywords:
population aging,
demographic dividend,
human capital,
economic growth

As total fertility rates (TFRs) decline globally and life expectancy rises, population aging presents significant economic challenges, including a shrinking working-age population and slower economic growth. This paper examines the impact of aging on economic growth trajectories in China, Hungary, Italy, Sweden, and the Republic of Korea, exploring how differing aging patterns influence economic outcomes. Using a general equilibrium model where agents optimize over an infinite horizon, the study projects GDP per capita and per worker over 60 years. The selected countries, each with TFRs below the replacement level for over three decades, are grouped based on demographic aging indicators. GDP trajectories are shaped by the ratios of the older and young populations to the working-age group and changes in workforce size. Human capital investment is a key component of the model, as each child, while they are young, receives human capital investment every year. This investment determines their future productivity in the workforce and, consequently, the productivity of the overall economy. To our knowledge, no prior research has examined human capital investments across multiple periods in models with infinitely optimizing agents and their cumulative impact on economic productivity. The findings suggest that aging trajectories significantly shape economic growth paths, underscoring the need for tailored strategies to sustain growth in different demographic contexts.

Online first publication date: 15 September 2025

Introduction

The question of how changes in fertility rates affect economic growth has long been of interest in economics. In his 1798 work, Malthus (for the reprinted edition of the original work, see Malthus (1986) [1798]) argued that the human population grows exponentially while resources only expand linearly, which would inevitably lead to constant famines and wars. In reality, the resources available per person have not decreased, and despite some setbacks, GDP per capita has steadily increased since Malthus's time. Malthus was correct in one sense: the population did indeed grow rapidly. According to World Bank data, by 2020, the global population was more than two and a half times larger than it was in 1960.

However, since the turn of the millennium, the population growth rate has been slowing, and several countries have experienced population decline over the last couple of decades owing to natural causes, namely, low total fertility rates (TFRs) that are not offset by declining mortality rates or net migration. Examples include Japan, Hungary, and Italy. The TFR[1] play a crucial role in this decline, as shown in Figure 1. In Europe and more recently in the East Asia and Pacific region the TFR tends to be lower than 2.1, which is considered to be the reproduction rate[2] in the literature (Teitelbaum–Winter 1985), represents the threshold for being able to reproduce the population.

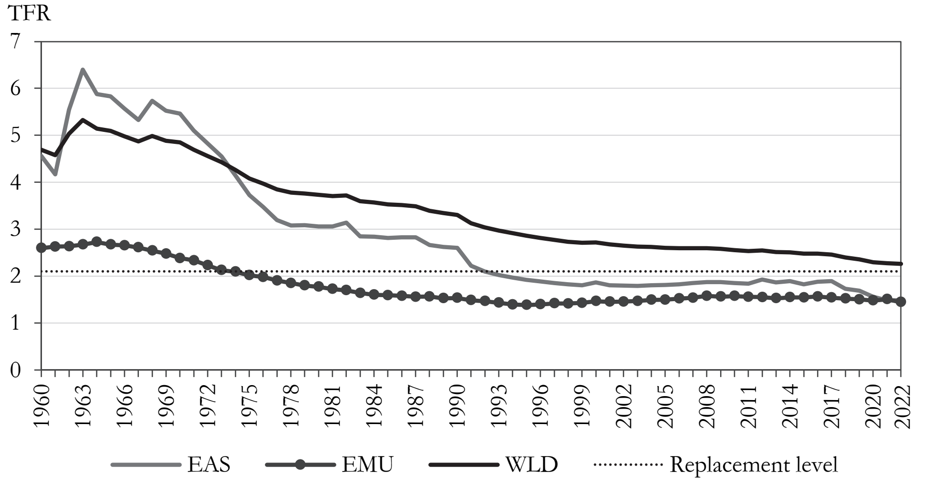
Nearly half a century ago, Ryder (1975) asserted that rapid population growth could only be a temporary state because, throughout human history, the long-term growth rate of the population has been nearly zero. Permanent growth on a global scale is unattainable. As a variable category, the population must eventually gravitate toward a stationary trajectory. Nevertheless, until recently, much of the literature treated population growth as a natural phenomenon, even though TFRs below the reproduction rate in many countries had already contradicted this assumption. Our article explores the development of GDP per capita and per worker using a general equilibrium model with infinitely optimizing agents.

[1] "The total fertility rate in a specific year is defined as the total number of children that would be born to each woman if she were to live to the end of her childbearing years and give birth to children in alignment with the prevailing age-specific fertility rates" (OECD 2024).

[2] 2.1 is referred to as the reproduction rate because the fertility level at which couples reproduce themselves, or in other words, replace themselves with their heirs (the replacement rate), is approximately 2.1 births per woman (OECD 2024).

Figure 1

The development of TFR for the global population (WLD), the Euro Area (EMU), and the East Asia & Pacific region (EAS)



Sources: authors' graph based on World Bank (2024) data.

As the TFR declines, births decrease and life expectancy at birth increases; consequently, more and more countries around the world face the aging of their societies. One manifestation of this is the increasing ratio of older people compared to the working-age population. An important research question is how this unprecedented demographic shift will impact long-term economic growth, the productivity of the working-age population, and living standards. Because demographic changes occur gradually and can be accurately estimated for the existing population. Forecasting the age structure is relatively straightforward. However, quantifying the complex economic processes that may either mitigate or amplify the effects of demographic changes is much more difficult.

When a country reaches the phase of declining fertility rates, which is not offset by net migration, the proportion of working-age people within the population increases. Known as the first demographic dividend[3], this phenomenon significantly boosts the economy (Lee–Mason 2006), helping explain the rapid economic growth of the Asian Dragons (Republic of Korea, Taiwan, Hong Kong, and Singapore) and China starting in the 1970s and 1980s. The continued decline of the TFR below the reproduction rate can remain a driving force for economic growth for a considerable time. However, when the previously large working-age cohort enters retirement, the old-age dependency ratio – the ratio of older dependents to working-age individuals – increases due to the growing older population. While ongoing investments in

[3] The first demographic dividend is a transitional period characterized by a relatively high share of the working-age population, which has the potential to accelerate economic growth (Lee–Mason 2006).

human and physical capital[4] may offset the high dependency ratio for a time (Gonand–Jouvet 2015, Mason–Lee 2006), there is concern that, eventually, GDP per capita may begin to decline.

Our article explores the development of GDP per capita and per worker using a general equilibrium model with infinitely optimizing agents. Models of this type, based on the broader neoclassical tradition, gained popularity in the 1980s and have since become crucial in macroeconomic modeling (Rebelo 2005, Stadler 1994). They effectively capture the complex impact of macroeconomic shocks, making it possible to track the consequences of the continuous decline in the TFR.

The exogenous variables describing the demographic elements in our model are fixed. We consider the ratio of the young and older adults to the working-age population, along with the temporal changes in the working-age population, as key variables. We track the temporal effects of these ratios on economic performance. Our study only focuses on European and East Asian countries where the TFR has been below the reproduction rate for at least three decades: China, Hungary, Italy, Sweden, and the Republic of Korea. We used the median version of the UN population forecast (United Nations 2022) to estimate future population ratios and modeled how changes in dependency ratios affect GDP per worker. If GDP per worker decreases along with GDP per capita, this becomes a clear indicator of economic decline, as it also reflects a decrease in efficiency. A distinctive feature of our model is that human capital is not an exogenous factor but an endogenous one (similar ideas can be found in Jones [2022]). Therefore, changes in population ratios imply corresponding changes in human capital.

Most previous studies have concluded that population aging will slow economic growth (see, for example, Choi–Shin 2015, Jones 2022, Kim et al. 2016, Maestas et al. 2023). Additionally, the primary aim of our paper is to highlight that the pattern of population aging and the resulting dynamic transformation of age structure trajectories also matter for long-term economic growth. Using our general equilibrium model, we show that countries with different aging trajectories can expect different growth paths over the next 60 years. Consequently, potential measures to maintain the economy or, optimistically, ensure growth will need to be formulated differently for each country.

The structure of the paper is as follows: after the introduction, the literature review of macroeconomic models based on neoclassical traditions will be provided, in which population dynamics influence output levels. Then the demographic trajectories of the countries studied are presented, followed by an outline of the authors' model. After presenting the model's results, the conclusions are summarized and the economic policy implications are highlighted.

[4] The effect of human and physical capital in continuing to support economic growth for some time after the first demographic dividend is exhausted is called the second demographic dividend. For more on this, see Prskawetz–Sambt (2014).

Literature review

Economists have long studied the effects of population changes on economic growth. For centuries, the field has been dominated by the impact of sustained population growth on living standards and long-term growth (to name just a few: Headey–Hodge 2009, Kremer 1993, Malthus 1986 [1798], Mankiw et al. 1992, Romer 1990, Smith 1999 [1776], Solow 1956). In many endogenous growth models, population size is decisive in the outcomes. A larger population typically means more researchers and highly skilled workers, which in turn leads to more innovations and higher living standards (see, for example, the models of Aghion–Howitt 1992, Jones 1995 and Romer 1990). In recent decades, however, many countries have experienced population decline and increasing aging. As a result, growth models, computable general equilibrium models, and empirical research have increasingly focused on what happens to economic growth when population growth becomes negative.

The works of Fougère et al. (2007, 2009) are considered pioneering in this area. In the latter study, using a general equilibrium OLG[5] model calibrated to Canadian data, they demonstrated that population aging does not necessarily lead to a decline in economic performance, assuming endogenous labor supply and human capital accumulation. They found that while aging reduced labor supply, the experience and skills accumulated by middle-aged workers improved labor productivity and increased life expectancy, encouraging young people to invest more in human capital. As a result, both present and future middle-aged cohorts will become more educated, which ultimately increases productive capacity and significantly reduces the costs of population aging. Choi–Shin (2015) also examined the impact of aging on economic growth in the Republic of Korea using an OLG model, in which the trajectory of human capital accumulation was also endogenous. However, they argued that population aging could significantly undermine growth potential, highlighting that their results were sensitive to how human capital is transferred across generations. Using a life-cycle model, Kolasa–Rubaszek (2016) predicted economic imbalances in the euro area's four largest economies due to a significant increase in the old-age dependency ratio, calling for deeper reforms in the eurozone's institutional structure to mitigate these imbalances.

In their semi-endogenous growth model, Sasaki–Hoshida (2017) found that negative population growth leads to positive and steady increases in welfare, as the capital available to each individual increases as the population decreases. However, they later revised their conclusions: assuming a CES production function within a Solow model framework, they found that, in some cases, long-term growth rates are determined only by the pace of technological progress, and the increasing capital–labor ratio resulting from negative population growth does not contribute to this.

[5] Overlapping generations (OLG) models. See in detail, for example, Auerbach–Kotlikoff (1987), Diamond (1965), and Nishiyama–Smetters (2014).

Kim et al. (2016) used a computable general equilibrium (CGE) population model to analyse Korea's regions and came to similar conclusions: the aging trend could cause an average GDP decline of 0.92%, but this damage could be mitigated by increasing educational investments in the 20–29 age group. Jones (2022) demonstrated in a growth model first characterized by exogenous population growth and later by endogenous fertility that negative population growth could be particularly harmful because it causes stagnation in knowledge and living standards, leading to a gradually disappearing population ("Empty Planet" result).

In contrast to earlier theories, Acemoglu–Restrepo (2017) argued that no negative relationship between population aging and slower GDP per-capita growth could be observed. One possible explanation for this finding is that society is forced to change technology in response to demographic shifts, which, for example, becomes more efficient using robots. Nevertheless, several recent empirical studies have confirmed the negative relationship (Kotschy–Bloom 2023, Lee–Shin 2019, Maestas et al. 2023, Ye et al. 2021).

Empirical data on aging in different countries

In our research, we pay special attention to the impact of aging on economic activity. To this end, we first collected data from countries where TFR has consistently been below the replacement level over the past decades. Despite declining mortality rates and positive net migration, low fertility rates drive these countries toward an aging society, and they are expected to remain so in the future unless the TFR increases above the replacement fertility rate.

The various dependency ratios reflect changes in the population's age structure. The increase in the old-age dependency ratio is the most obvious sign of an aging society, while the decrease in the youth dependency ratio also suggests that, in the long term, aging of the society is to be expected. These two dependency ratios were key categories in our model, with a slight deviation from the usual convention: we considered individuals aged 0–18 as "young", instead of the more commonly used age range of 0–15. We quantified the annual changes in the age structure based on the population's median estimates by age from the United Nations (2022), using actual data for 2021. We projected the estimates over a 60-year period, which encompasses the expected lifespan of the current young adults. The countries studied were typically aging nations, expected to face even more pronounced aging over the next 60 years, according to the forecasts. The estimated changes in the dependency ratios for the selected countries are shown in Appendix 1 Figures A3, A4 and A5.

The pace, extent, and trajectory of population aging exhibit significantly different patterns worldwide, suggesting that its impact on economic growth may also vary. In some countries, the TFR has remained relatively stable, either at a higher or lower level, for an extended period. In other countries, however, the decline in TFR has accelerated over the past decade, temporarily leading to an increase in the relative size of the working-age population and creating a favorable age distribution that boosts production (the first demographic dividend). After this phase, however, population aging is expected to accelerate in these countries. Based on the expected trajectories of youth, old age, and total dependency ratios[6], we identified five different types of countries in terms of aging patterns. The main characteristics of these groups and the countries they comprise are shown in Table 1.

In the first group, we classified countries that are aging very slowly, where the old-age dependency ratio will gradually rise to around 60 over the next 60 years, but the proportion of young people will remain relatively high throughout, causing the total dependency ratio to approach 100 in the long term. Sweden is an outstanding example of this type. The aging process is faster among the countries classified in the second group, such as Hungary, where the proportion of young people is expected to stabilize around 30, while the proportion of older adults will increase and is projected to reach 60 older dependents per 100 working-age individuals within the next 40 years. The third group mainly includes countries with a long history of low TFR, such as Italy. Consequently, aging is already significant in these countries and is expected to intensify over the next 40 years before slowing down. In this group, the old-age dependency ratio could rise to 70, while the total dependency ratio may exceed 110. The fourth group includes countries where the proportion of young people is still relatively high but is rapidly decreasing, leading to substantial and sustained aging over the next 60 years. In the long term, the ratio of older dependents per 100 working-age individuals could exceed 80, as seen in China. This phenomenon is even more pronounced in the fifth group, as exemplified by Korea. In this case, the youth dependency ratio is expected to fall to a critically low level, remaining below 30, whereas the total dependency ratio could rise to an extremely high level, surpassing 100 according to projections.

The calculated and projected aging trends for the age groups (see in Appendix 1 Figures A3, A4 and A5) could naturally change if birth rates, migration balance, life expectancy at birth, or retirement age – and consequently the age limit for the active period – differ significantly from the assumptions.

[6] In our paper, the young-age dependency ratio is defined differently than usual: it represents the number of persons under the age of 19 per 100 working-age persons, i.e., those aged 19–64. The old-age dependency ratio is defined as the number of persons older than 64 per 100 working-age persons, i.e., those aged 19–64. The total dependency ratio is the sum of the young-age and old-age dependency ratios. When grouping the countries in Table 1, we rely on our definition.

Table 1

Five country groups according to their aging trends

Groups	Young-age dependency ratio	Old-age dependency ratio	Total dependency ratio	List of countries[a)]	General characteristics of aging
Group 1	Decreasing trend but remains relatively high (always >30)	Very slow aging, rising to around 60, within 60 years	Slowly and evenly approaching 100	**Sweden**, United Kingdom, Canada	Very slow aging
Group 2	Stabilizes around 30 in. the long term, slightly above 30	Slow increase over the next 40 years, approaching or reaching 60	Slow increase over the next 40 years, approaching or reaching 100	**Hungary**, Croatia, Germany, Austria, and Lithuania	Slow aging
Group 3	Starts below 30 and stabilizes around 30 in. the long term	Drastic increase over the next 40 years, exceeding 70	Drastic increase over the next 40 years, exceeding 110	**Italy**, Spain, Portugal, and Japan	Aging is already present, will further intensify but the process will eventually slow down
Group 4	Quickly falls below 30	Sustained increase over the next 40 years could exceed 80	Starts below 60, sustained increase over the next 60 years, exceeding 110	**China**, Thailand, Singapore, and Taiwan	Strong, sustained aging
Group 5	Very low ratio of young people (always <30)	Sustained, drastic increase to over 100 (!)	Sustained, drastic increase over the next 60 years, jumping from around 50 to 130 (!)	**Republic of Korea**, Hong Kong	Very rapid and sustained aging

a) The name of the country selected for analysis as a representative from each group is in bold.
Sources: authors' contribution based on United Nations (2022) data.

The model

Our main research question is what long-term impact demographic aging is likely to have on economic performance, specifically on GDP per capita, and beyond that, on the productivity of the working-age population. Based on the analysis of previous data, we formulated the following research hypothesis: if the fertility rate remains below the replacement level for 10–20 years after initially falling below that level, and if net migration does not compensate for this, then while it may initially (even over a 30–50 year period) increase per-capita output, in the longer term it will negatively affect not only per-capita output but also output per worker.

Another research question is whether we can expect significant differences in the growth performance of countries experiencing different trajectories of aging over the next 60 years. We investigate whether Korea, with more drastic aging characteristics, and China, which is also aging but with less dramatic trends, will likely follow similar or different GDP trajectories in the future. Similarly, we examine Hungary and Italy, which belong to two different groups in Table 1 but have had relatively low fertility rates for a long time, to understand what economic growth paths they can expect in the long term. We also ask whether Sweden, which is projected to experience the slowest aging trend compared to the other countries studied, can turn this into an economic advantage.

Our model aims to investigate how the differing developments of the first demographic dividend cause variations in GDP per capita and productivity trajectories. Additionally, we seek to understand how the most important factor in our case, human capital investment, which results in the second demographic dividend, can mitigate the decline in per-capita output and productivity. In our model, productivity can be increased through physical investment and human capital investment. This idea aligns with Becker's quantity–quality trade-off (Becker 1960), as when a family has fewer children to raise on average, they can allocate more (financial and time) resources to each child. Therefore, we include the expected evolution of the age structure in our model, as this influences human capital investment.

To test our hypotheses, we developed a general equilibrium model that includes agents that optimize infinitely. However, unlike the standard model framework, our model features the following distinctive factors:

- The accumulation of human capital across generations is endogenous: If economic agents want to promote the development of human resources, they must invest in the knowledge and abilities of children, as this will have a spillover effect on the knowledge of workers (for different representations of human capital accumulation alongside utility-maximizing agents, see Choi–Shin 2015).
- The spillover effect of human capital investments plays a critical role in our model. Throughout the 18 years when our model's agent is still a "child", there are continuous human capital investments, which will determine the productivity of the agent once they enter the workforce, and consequently, the productivity of the entire economy (see later equation (9)). In our readings, we have not come across any literature that tracks human capital investment over multiple periods in models with agents optimizing infinitely, and then examines its combined effect on economic productivity.
- To improve the knowledge and abilities of children, economically active agents in the labor market not only need to spend money (see later equation (2)), but they must also sacrifice a portion of their leisure time (see later equation (4)).

In other words, it is not sufficient to simply allocate part of their income to educational expenses; personal presence, assistance, and involvement are also necessary for the development of children's knowledge and abilities (the incorporation of time spent on child-rearing into the model framework is also reflected, for example, in Blundell et al. [2018]).

- In our model, the older population finances its consumption through the transfers received. The necessary funds for these transfers are generated by the active workforce.
- The ratio of young people and older adults relative to the working-age population, as well as the changes in the growth rate of the working-age population, were introduced as exogenous variables in the model, based on the United Nations (2022) median projection for the next 60 years.

We intentionally kept the model's basic structure very simple level to focus on the impact of demographic aging on economic performance. This objective also guided the approach of utilizing the opportunities provided by macroeconomic models to trace the differences between the considered economies primarily to demographic factors and those related to human resource accumulation. Consequently, during the calibration of the model, the core parameters are identical for each economy; however, economic agents in different countries face distinct decision-making environments, leading them to make divergent decisions. These differences arise from variations in fertility rates, demographic ratios, and educational expenditures as determined by fiscal policymakers.

The economy includes only two types of economic agents: consumers and firms. These two types of agents interact in just four markets: the goods market, the asset market, and the markets for the two production factors, labor and capital. The details of the model are provided in equations (1) to (9) below, and in Appendix 2 equations (A1) to (A8).

The representative consumer derives utility from consumption and leisure (see equation (1)). She also gains satisfaction from her offsprings' skill and knowledge level, represented by the variable h_t, which also affects her lifetime utility. The objective function is written as

$$U = \sum_{t=1}^{\infty} \beta^{t-1} \left(\frac{c_t^{1-\sigma}}{1-\sigma} + \Psi \frac{(1-l_t-lch_t)^{1-\eta}}{1-\eta} + \Phi \frac{\left(\frac{CH_t}{N_t} h_t\right)^{1-\nu}}{1-\nu} \right), \tag{1}$$

where c_t, l_t and lch_t denote consumption, labor supply, and time spent with the children, respectively, CH_t is the number of individuals in the child cohort, and N_t represents the number of agents in the active adult population.

In each period, an individual receives labor income and can use the proceeds from her previously accumulated savings to finance her consumption, her share of educational spending ($e_t = educ_t y_t$, where $educ_t$ is the total government expenditure on education [as a percentage of GDP]), pension contributions ($tr_t p_t$), and additional savings (s_{t+1}). In the term $tr_t p_t$, p_t represents the ratio of the population above 64 years of age to the number of active adults, while tr_t denotes the average pension transfer.[7] For simplicity, we do not include a fiscal policy decision-maker in the model; thus, economic agents must accumulate the funds necessary to finance public spending.

While searching for the optimal path of the variables, she must consider the time series of the following budget constraints (see equation (2)):

$$w_t ha_t l_t + (1 + r_t)s_t + inh_t = (1 + ch_t x)c_t + e_t + s_{t+1} + tr_t p_t, \quad (2)$$

where ha_t is the human capital (a set of skills and knowledge) of an adult agent at a period t, and inh_t denotes a form of inheritance (see equation (3)) related to the variation in the number of active adult agents, and r_t is the real interest rate.

$$inh_t = \frac{N_{t-1} - N_t}{N_t}(1 + r_t)s_t. \quad (3)$$

We assume that spending on education and time spent with children creates skills and knowledge among individuals in the child cohort through the following process:

$$\frac{CH_t}{N_t} h_t = a_{h,t} lch_t^{\theta}(e_t)^{1-\theta}. \quad (4)$$

The important features of equation (4) are that, ceteris paribus, (i) a decline in the number of children, (ii) an increase in the active adult population, or (iii) an increase in the overall effectiveness of the education system, a_{ht}, can raise the human capital level of a child. Moreover, the ratio CH_t/N_t represents the youth dependency ratio.

The representative firm uses labor and capital to produce output in a perfectly competitive environment. The per-capita production function (relative to the active adult population) takes the following form (equation (5)):

$$y_t = a_t k_t^{\alpha}(ha_t l_t)^{1-\alpha}. \quad (5)$$

Markets clear. In the market for goods and services (see equation (6)), per-capita output equals the sum of consumption, per-capita investment, education spending, and pension transfers (we assume that retired agents spend their pension income on consumption).

$$y_t = (1 + ch_t x)c_t + i_t + e_t + tr_t p_t, \quad (6)$$

where

$$i_t = (1 + n_{t+1})k_{t+1} - (1 - \delta)k_t. \quad (7)$$

In equation (8), n_t denotes the exogenous growth rate of the working-age population based on data from the United Nations (2022).

$$1 + n_t = \frac{N_{t+1}}{N_t}. \quad (8)$$

In the factor markets, the market clearing condition states that at a given factor price, the supply of an input equals the demand for the input. Furthermore, the total savings finance the newly acquired capital.

[7] We assume that the transfer is a constant gamma fraction of the income (see in Appendix 2 equation A8).

An essential element of the model is that the human capital of children entering the labor market in period t has a spillover effect on the human capital of the agents already in the market. This effect can be represented by the following function:

$$ha_t = \kappa\left(\frac{1}{18}\sum_{s=t-18}^{s=t-1} h_s\right) + (1 - \delta_h)ha_{t-1}. \quad (9)$$

Since a child's human capital depends on both educational expenditures and adult efforts, this functional form ensures that (i) an entire segment of the time series for these variables can influence the human capital of an active adult and (ii) the impact of increased educational expenditures or adult efforts on the human capital of an active adult manifests with an elongated temporal lag.

Under these conditions and at a given path for the exogenous variables $educ_t, n_t, p_t$ and ch_t, the equations and the first-order conditions (4)–(5)–(6)–(7)–(9) and in Appendix 2 (A1)–(A8) determine the optimal path of the endogenous variables $y_t, c_t, l_t, lch_t, tr_t, e_t, h_t, ha_t, k_{t+1}, i_t, w_t, r_t^K$ and $1 + r_{t+1}$.

The parameter values used during the model calibration are provided in Appendix 1 Table A1.[8] The value of $educ_t$ was calculated for the respective country based on data from the World Bank database, while the demographic indicators were determined using actual data from the United Nations (2022) until 2021, followed by median estimates projected 60 years into the future. These projections took into account expected trends in fertility rates, net migration and mortality rates.

Results

The graphs corresponding to the results of our model are presented in Appendix 1 Figures A6 and A7, with all figures showing the development of the examined variables over a 60-year period from 2022 to 2081 relative to the 2022 levels. This is a relatively long period for a simulation model, during which several real-world changes could occur that may alter the fundamental relationships in the model. However, the 60-year time horizon enables us to examine the long-term effects of demographic aging in the five selected countries. Our results highlight that, although the old-age dependency ratio increases in all the countries studied (see in Appendix 1 Figure A4), the rate of this increase and the accompanying TFR values vary significantly. The diverse aging patterns are further supported by the fact that, among the selected countries, only Sweden's population is expected to continue growing over the next 60 years. In contrast, the population growth rate in the other four examined countries is projected to remain below 0% throughout this period (see in Appendix 1

[8] Based on the sensitivity analysis we conducted, we can conclude that changes to the model's key parameters within certain boundaries do not affect the dynamics of GDP per worker, but only its level. Let us consider a few parameters intervals for the variables related to human capital. For instance, if the ν parameter varies within the range of 1.5–3.5, the κ parameter within 0.05–0.085, and the $a_{h,t}$ parameter within 2.5–4.6, then, ceteris paribus, our model's projection predicts the exhaustion of the demographic dividend – i.e., the transition of GDP per-worker growth into decline – at the same point in time.

Figure A1). However, the proportion of the working-age population – defined in this case as individuals aged 19–64 – is expected to decline across all the countries, although the degree of decline varies significantly. By 2080, this proportion is anticipated to be between 50% and 55% in Sweden and Hungary, 45%–50% in China and Italy, and an exceptionally low 40%–45% in Korea (see in Appendix 1 Figure A2).

When looking at per-capita GDP, its trajectory over the 60-year period shifts from increasing to decreasing in all five countries (see in Appendix 1 Figure A6). It is no coincidence, however that the most pronounced decline is first observed in Italy, where per-GDP was already relatively low at its highest point compared to 2022. This is the country where the old-age dependency ratio shows the most significant and early increase in the projections (parallel with the rapid decline in the proportion of the working-age population [see in Appendix 1 Figure A2]) and remains the highest until 2047. Although Hungary's old-age dependency ratio remains lower and the share of the working-age population to the total population is higher than Italy's throughout the period (see in Appendix 1 Figures A2 and A4), Hungary is still the country with the second fastest declining per-capita GDP (see in Appendix 1 Figure A6). In Hungary's case, the old-age dependency ratio does not provide a clear explanation for the rapid decline, as its value is not among the highest of the five countries, and future projections do not show a sharply increasing trend. Hungary's youth dependency ratio is relatively high in this model (see in Appendix 1 Figure A3), and paradoxically, its sustained level at the beginning of the forecast period proves to be a disadvantage for Hungary, as it hinders the realization of the first demographic dividend, which is still moderately present in Italy.

The expected increase in per-capita GDP in China and Korea over the past three decades is primarily driven by the ongoing sharp decline in the youth dependency ratio and the growing share of the working-age population relative to the total population, corresponding with the decreasing TFR. This trend continues to drive economic growth through the first demographic dividend. Additionally, in Korea, where the youth dependency ratio is even lower than China's, the total dependency ratio starts to rise significantly later due to historical demographic trends (see Figure A5), which delays the decline in GDP. Although China's relative economic growth at the start of the projection period is much greater than Korea's, this does not translate into a larger absolute increase because China's GDP per capita in the base year 2022 was substantially lower than Korea's.

Sweden is a notable case with its unique trajectory in per-capita GDP. Throughout the examined period, Sweden maintained a high, but only slightly increasing, old-age dependency ratio (see in Appendix 1 Figure A4), while its youth dependency ratio was also relatively high (see in Appendix 1 Figure A3), with only modest decreases and periods of increase. Furthermore, the share of the working-age population with the total population is constant at around 57% for a longer time period (see in Appendix 1 Figure A2). This indicates that Sweden's age ratios have long been relatively stable, and the TFR has not fallen as sharply as in the other four countries. Consequently, Sweden's per-capita GDP remains relatively stable, declining only modestly after 2070.

According to our model's results, the demographic processes outlined above negatively affect not only per-capita GDP but also the growth rate of GDP per worker in the long term, meaning that productivity could be adversely impacted. This is noteworthy because none of the dependency ratios directly affect production per worker. However, in our model, the youth and old-age dependency ratios indirectly influence both human capital and physical capital per worker. Jones (2022) found a similar relationship, explaining that the indirect connection is because the amount of human and physical capital depends on the knowledge and capital accumulated by people, which is primarily created by the active population. Therefore, fewer working people accumulate less of this type of capital. In our model, the growth trajectories also depend on the timing and magnitude of the dependency ratios, as shown in Appendix 1 Figure A7.

In Figure A7, we also consider 2022 as the base year and compare the GDP per worker relative to that year. The most considerable initial growth can be observed in China, where, except for the first four periods, the total dependency ratio remains the lowest among the countries in our sample until the 2050s (see in Appendix 1 Figure A5). Korea also shows rapid growth, and by the end of the analysed time period, it has the highest GDP per worker relative to the 2022 level (see in Appendix 1 Figure A7). The number of dependents per working-age individual is initially still comparatively low in Korea (see in Appendix 1 Figure A5), meaning that the country is likely still benefiting from the positive effects of the first demographic dividend. Furthermore, the quantity–quality tradeoff resulting from the low number of children leads to high human capital accumulation (the highest among the countries studied), allowing Korea to sustain productivity growth for a relatively long time, thanks to the positive second dividend. However, it is also evident that by the end of the examined period, a negative GDP growth rate per worker in these countries has become inevitable. This occurs when the decline in the proportion of the working-age population within the total population can no longer be offset by human capital improvements. At this point, the demographic impact will most strongly impede economic growth, leading to the "demographic debt."

Sweden maintains positive GDP per-worker growth for the longest time in our sample, with a negligible decline at the end of the period. The reason for this, in terms of per-worker and per-capita production, is that Sweden's total dependency ratio initially stagnates and only shows slow growth afterward. Therefore, the burden on the working-age population does not increase as drastically as it does in other countries.

Hungary occupies a middle position, where the favorable effects can be sustained for nearly 40 years. However, the slow, continuous aging process eventually diverts resources and leads to negative GDP growth per worker in the long run. The situation is more severe in Italy, where the population is already very old, and both the old-age and total dependency ratios are high, with further deterioration expected. Italy is also the first country to observe a negative shift in productivity growth rates. Due to the shrinking number of young people and the draining of resources by the older population, the growth potential quickly dissipates.

Our results can easily be extended to other countries in the groups shown in Table 1. Our model specified the future trajectory of dependency ratios and the level of education expenditure as a percentage of GDP as exogenous variables. Considering that there is not much significant difference in the level of government expenditure on education among developed and relatively developed countries, the aging pattern is fundamentally the determining factor in shaping the expected time paths of both GDP per capita and per worker in our model. From this perspective, the United Kingdom and Canada belong to Group 1, Croatia, Germany, Austria, and Lithuania to Group 2, Spain, Portugal, and Japan to Group 3, Thailand, Singapore, and Taiwan to Group 4, and Hong Kong to Group 5.

We have demonstrated that if a country expects slow aging (as in Group 1), if aging is already strongly present and will intensify before slowing down (Group 3), or if aging is rapid and persistent (Group 5), then long-term economic growth will follow fundamentally different paths, and the drivers of growth will also evolve differently.

Conclusions

Our general equilibrium model, with infinitely optimizing agents, has shown that the prolonged decline of the TFR and its remaining below the reproduction rate over an extended period will eventually turn the first demographic dividend into demographic debt. This demographic debt is unavoidable, regardless of the trajectory by which a country reaches TFR values below the reproduction rate, as long as these values characterize the country's demographic situation for an extended period of time.

However, the path a country takes to reach the era of demographic debt is crucial. A rapid and dramatic decline in the TFR, provided that large cohorts from previous periods remain in the workforce and the old-age dependency ratio has not yet significantly increased, can continue to boost GDP per capita. This may create the perception that the TFR can be reduced "without consequence" for an extended period, as long as a country invests heavily in its human capital. Eventually, however, the large working-age cohort becomes inactive, at which point per-capita GDP in our model begins to decline.

One might think that the increased number of dependents relative to workers would only result in a decline in per-capita GDP. However, our model has shown that the negative effects also impact productivity. If the TFR remains below the reproduction rate for a prolonged period and net migration does not compensate for it, output per worker will also fall over time, as we hypothesized at the beginning of our paper. Since both human and physical capital per worker in our model are indirectly influenced by the youth and old-age dependency ratios, the rapidly declining proportion of the working-age population within the total population can no longer be offset by developing workers' human capital. As a result, the demographic impact will hinder economic growth and production efficiency.

Our results support the prevailing position in the literature: in the long run, demographic aging will impede economic growth and, in some cases, even lead to a decline in productivity. Our model has revealed the factors that explain why China and Korea, which experience different aging patterns, may nevertheless follow GDP trajectories that are much less distinct than those of Hungary and Italy, which also belong to different groups in Table 1. It also clarifies what gives Sweden, which is also placed in a different group, a long-term economic advantage compared to its continental counterparts.

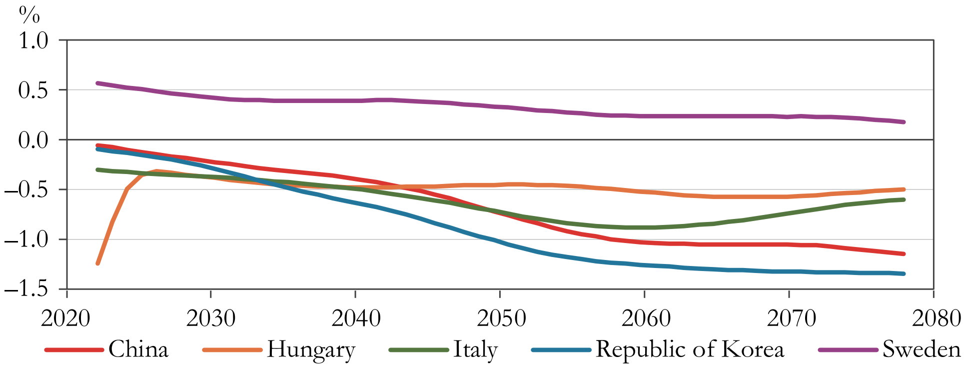
We believe our study introduces two new elements. In our readings, we have not encountered any research that tracks human capital investment over multiple periods in models with agents optimizing infinitely, and then examines its combined effect on the economy's productivity. Additionally, when examining the role of demographic aging in economic growth, we placed special emphasis on the evolution of per-capita GDP and changes in GDP per worker.

Although by the end of the projection period, all the countries studied will experience a declining trend in per-capita GDP, the path a country takes to reach this point and the extent of the decline are crucial. While the relationships in our model are fixed, significant changes in technological progress and demographic ratios could override these relationships. In this case, countries that manage to avoid significant economic downturns and whose TFR values do not decline to levels that would signal a drastic reduction in the labor force will return to previous levels of output indicators more easily.

Appendix 1

Figure A1

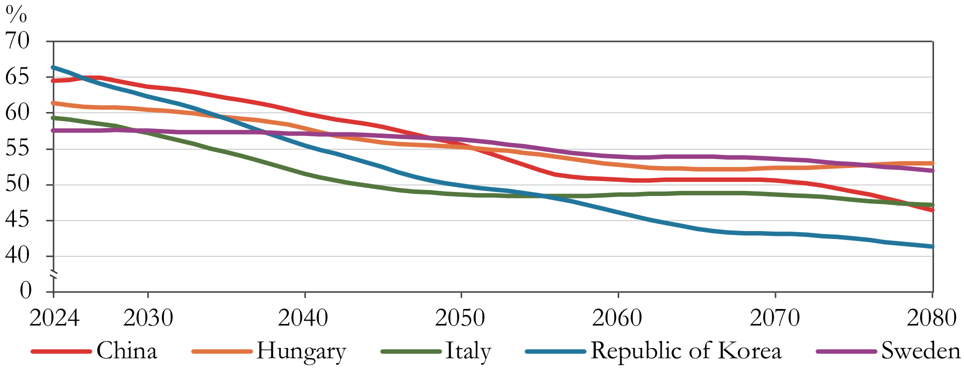
Population change



Sources: authors' contribution, based on data from the United Nations (2022).

Figure A2

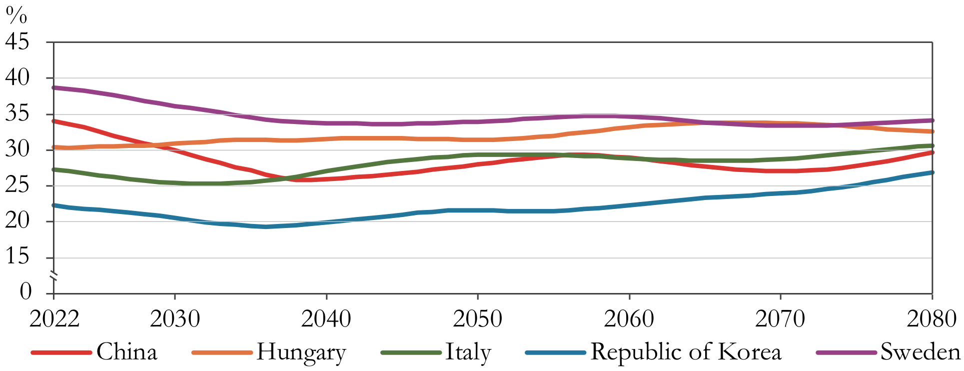
Working-age population (19–64) as a share of the total population



Sources: authors' contribution, based on data from the United Nations (2022).

Figure A3

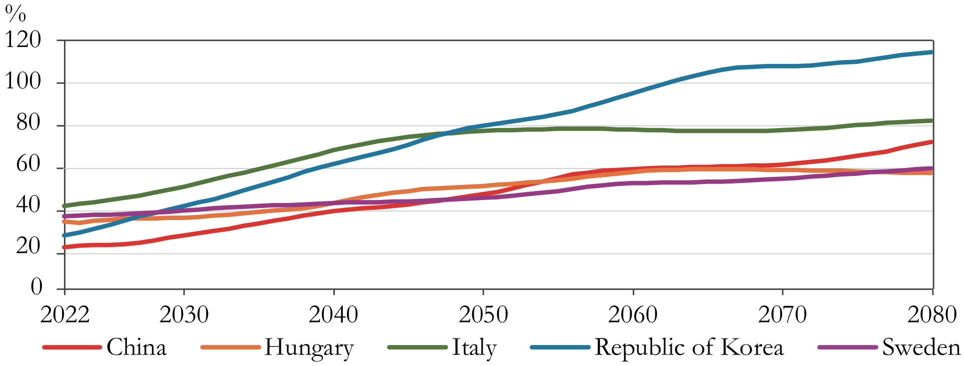
Youth dependency ratios



Sources: authors' contribution, based on data from the United Nations (2022).

Figure A4

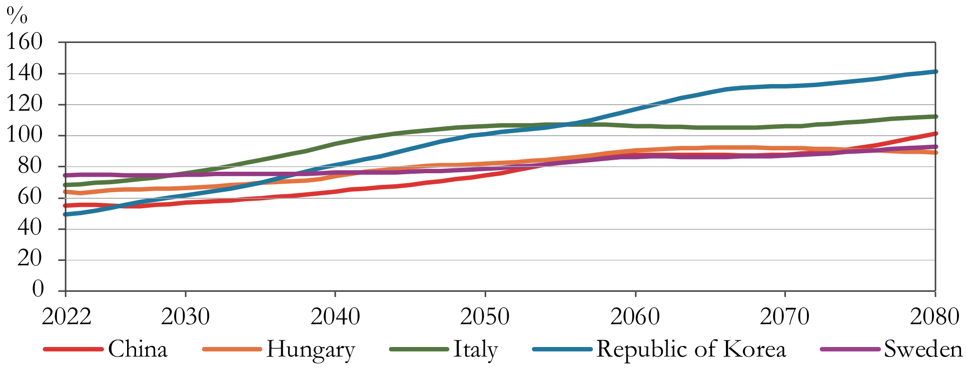
Old-age dependency ratios



Sources: authors' contribution, based on data from the United Nations (2022).

Figure A5

Total dependency ratios



Sources: authors' contribution, based on data from the United Nations (2022)

Figure A6

The evolution of per-capita GDP according to our model's estimate (2022 = 100)

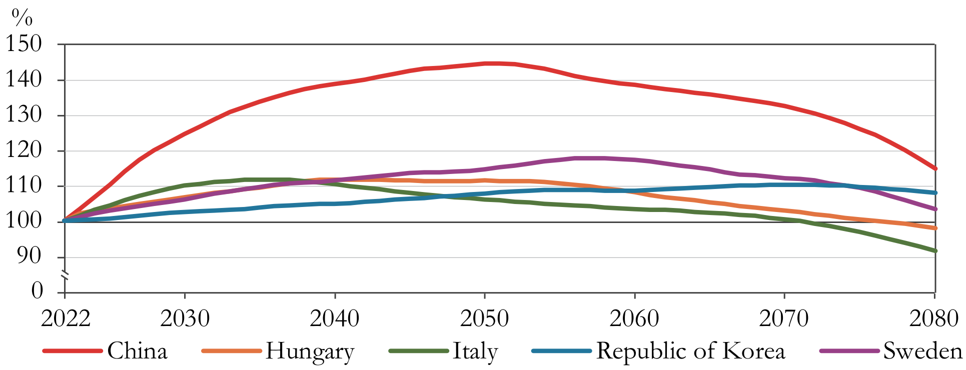


Figure A7

The evolution of GDP per worker according to our model's estimate (2022 = 100)

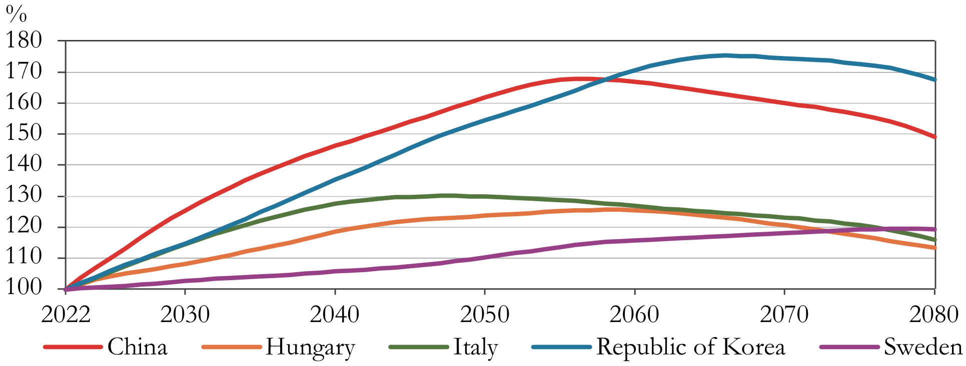


Table A1

Parameter values

Parameter notation	Value	Parameter notation	Value	Parameter notation	Value
β	0.98	ν	2.00	α	0.33
σ	1.00	x	0.50	δ	0.05
Ψ	1.00	$a_{h,t}$	2.50	κ	0.05
η	0.75	θ	0.35	δ_h	0.05
Φ	1.00	a_t	1.00	γ	0.50

Appendix 2

First-order conditions, constraints and definitions of the model

$$\Psi(1-l_t-lch_t)^{-\eta} = \frac{c_t^{-\sigma}}{(1+ch_t x)} w_t ha_t \quad \text{(A1)}$$

$$\Psi(1-l_t-lch_t)^{-\eta} = \Phi\theta \frac{(ch_t h_t)^{1-\nu}}{lch_t} \quad \text{(A2)}$$

$$\frac{c_t^{-\sigma}}{(1+ch_t x)} = \beta(1+r_{t+1}) \frac{c_{t+1}^{-\sigma}}{(1+ch_{t+1} x)} \quad \text{(A3)}$$

$$w_t = (1-\alpha)\frac{y_t}{ha_t l_t} \quad \text{(A4)}$$

$$r_t^K = \alpha \frac{y_t}{k_t} \quad \text{(A5)}$$

$$1 + r_{t+1} = r_{t+1}^K + (1-\delta) \quad \text{(A6)}$$

$$e_t = educ_t y_t \quad \text{(A7)}$$

$$tr_t = \gamma y_t. \quad \text{(A8)}$$

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