Working Paper (WP/24-09)

China Economic Insights

Macroeconomic Implications of China's Population Aging: A Dynamic OLG General Equilibrium Analysis

Fan Zhai

September 2024

[This page is intentionally left blank]

Macroeconomic Implications of China's Population Aging:
A Dynamic OLG General Equilibrium Analysis

Prepared by Fan Zhai[1] [2]

Reviewed by Jae Young Lee; Authorized by Hoe Ee Khor

September 2024

Abstract

This paper investigates the macroeconomic impacts of China's population aging using a global computable general equilibrium model with overlapping generations. Incorporating the population projections made by the UN, the model finds that the expected demographic changes will reduce China's average annual economic growth rate by 1.1-1.4 percentage points over the next five decades. Per capita income growth would also slow due to a faster decline in the workforce relative to the population. Raising retirement ages is expected to mitigate the negative effect, but the magnitude of its impact is found to be limited.

JEL classification: C68, E21, J10

Keywords: China, population aging, overlapping generations model

[1] Author's e-mails: fzhai.fan@amro-asia.org.

[2] The author would like to thank Jorge A. Chan-Lau, Jae Young Lee and Hoe Ee Khor for useful comments. All remaining mistakes are the responsibility of the author.

Abbreviations

CES	constant elasticity of substitution
GDP	gross domestic product
GEM	Global Economic Model
OLG	overlapping generations
PAYG	pay-as-you-go
TFR	total fertility rate
UN	United Nations

Contents

Figures

Tables

[This page is intentionally left blank]

I. Introduction

China's reform and opening-up over the past four decades, along with favorable demographic dynamics, have propelled rapid economic growth, elevating it to the status of an important global economic power. However, the population dynamics have turned from positive to negative in China. After working age population (ages 15–64) peaked in 2013, China's total population fell by 850,000 people in 2023 to 1.41 billion, marking its first drop since 1961. In 2023, the country's population fell for a second consecutive year, dropping by 2.08 million, or 0.15 percent. The declining fertility rates and increased longevity have led to a rapidly aging population. Elderly population aged 65 and above reached 209.78 million by the end of 2022, accounting for 14.9 percent of the total population, making China an "aged society" by UN standards.[3]

The dramatic demographic shift is expected to persist in the coming decades, bearing significant economic and social consequences. Population aging reduces labor supply and may lower labor productivity in its initial stages. Investment is likely to be depressed by a rising capital-labor ratio and a lower return to capital relative to return to labor. As pension and healthcare expenditures escalate alongside the rising proportion of elderly citizens, the social security system may face long term financial challenges, calling for structural reform in the labor market and public finance.

Starting with the seminal work of Auerbach and Kotlikoff (1987), it has become the convention to use large-scale numerical overlapping generations (OLG) models to analyze the economic impacts of demographic transitions and the associated fiscal policy.[4] In recent years, OLG models have also been utilized to investigate China's population aging issue. Cheng (2003) simulates the effects of fertility changes on the Chinese economy using a general equilibrium OLG model. It shows that low fertility rates lead to lower returns to capital and higher returns to labor, suggesting that the fall in demand for capital due to labor shortage is greater than the fall in supply due to the dissaving of the elderly. Moreover, the paper finds no significant link between demographic structures and per capita income growth.

Some recent studies focus on the effects of social security reform within the context of China's demographic transition. Song et al. (2015) employed an OLG model with endogenous labor supply to analyze the welfare and intergenerational distributional effects of alternative pension reforms in China. Their findings suggest that a fully funded reform of China's pension system harms current generations with marginal gains to future generations. He, Ning and Zhu (2019) develop an OLG model with idiosyncratic income risks to study the impacts of population aging and pension reform on savings and the labor supply in China. Their results indicate that the pension reform and rapid aging together can explain approximately 60 percent of the increases in household saving rate and labor supply from 1995 to 2009.

---

[3] The United Nations defines a country as "aging" if 7-14 percent of its population is aged 65 or older. A country is considered "aged" if this demographic makes up 15-20 percent of the population, and "super-aged" if it exceeds 21 percent.

[4] See, for example, Auerbach and Kotlikoff (1987) and Kotlikoff, Smetters and Walliser (2007) for the U.S., Auerbach et al. (1989) for four OECD countries (the U.S., Japan, Germany, and Sweden), Miles (1997) for the U.K. and European countries, Ríos-Rull (2001) for Spain, Muto, Oda and Sudo (2016) for Japan and Kwon (2017) for Korea.

This paper aims to provide a quantitative analysis of the potential macroeconomic consequences of China's demographic shifts in the coming decades. A two-region global general equilibrium model is used to simulate the scenarios of demographic changes and possible policy adjustments in China. The major conclusion of the simulations is that population aging will weaken China's economic growth and put pressures on public finance. The simulations indicate, under the UN's medium variant population projection, China's annual average growth rate over the next fifty years would be trimmed by 1.1 percentage points because of the expected contraction in population and workforce. The growth deceleration would escalate to 1.4 percentage points under an alternative population projection with low variant fertility. Per capita income growth would also be slower as the supply of productivity-adjusted effective labor shrinks faster than population. The fiscal position is expected to deteriorate as the pension burden could increase by roughly a half due to the demographic changes. As raising retirement ages can only mitigate these negative effects to a limited extent, further structural reforms will be necessary to enhance labor productivity and ensure fiscal sustainability, thereby addressing the challenges of population aging.

The paper is organized as follows. Section 2 overviews China's demographic trends. This is followed by a description of the OLG model and its parameter values used in this paper. Section 4 discusses the simulation scenarios and presents simulation results. The final section offers conclusions.

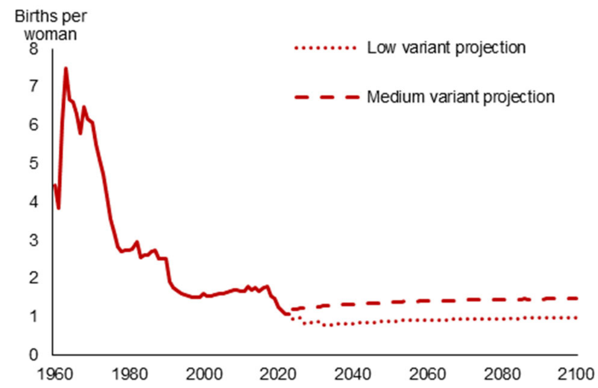
II. Demographic Trends

The simultaneous decline in fertility and mortality, both historically and projected for the future, will significantly reshape China's demographic landscape. Prior to the well-known one-child policy that came into effect in 1979, China had already enforced stringent family planning policies in the early 1970s (Zhang, 2017). As a result, China's total fertility rate (TFR) declined drastically from 5.7 in 1969 to 2.7 in 1978. With the introduction of the one-child policy, the TFR fell below the replacement rate of 2.1 in early 1990s and ranged between 1.5-1.8 in 1995-2019 (Figure 1). Despite the relaxation of one-child policy in 2013 and 2016, China TFR continued to fall, plummeting to 1.09 in 2022 (Li, Wang and Zhang, 2023). The COVID-19 pandemic may have caused some short-term disruption in family planning and distorted the fertility rate. However, even before the pandemic, China's TFR already fell to 1.5 in 2019, a level known as the threshold of "low fertility trap".

The UN's "medium variant" baseline projection assumes the China's fertility rate will reverse its declining trend, rising to 1.39 in 2050 and 1.44 in 2100 (Figure 1). However, this projection diverges from historical evidence. In most of China's neighboring economies in East Asia, the TFRs stagnate or continue to fall even when they are already at very low levels. Under an alternative "low variant" fertility rate projection, fertility is projected to be 0.25 children per woman below the fertility in the medium variant over 2022-26, 0.4 children per woman over 2027-31, and 0.5 children per woman over 2032-2100. This assumption may be more realistic in light of the prevailing low birth rates in East Asian economies - Korea, Hong Kong, Taiwan Province of China and Singapore all currently have TFRs at or well below one.

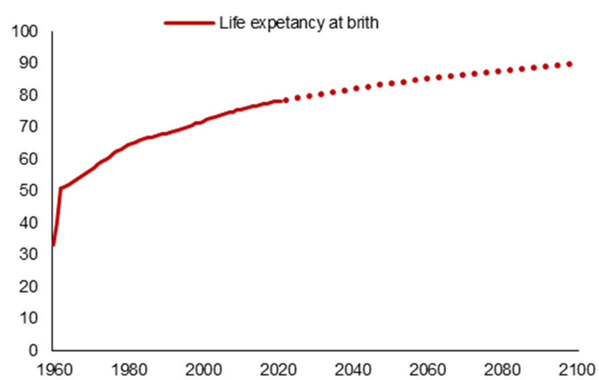
Mortality rate is another critical variable affecting population dynamics. Reflecting the improved medical care and living standard, China has witnessed a rapid increase in longevity since the initiation of its reform and opening-up policies. Life expectancy at birth has surged from 63.2 years in 1978 to 78.1 years in 2020. With expectations of continued reductions in mortality rates, the UN predicts that China's life expectancy at birth will rise to 83.8 years by 2050 and to 90.2 years by 2100 (Figure 2).

Figure 1. Total Fertility Rate of China, 1960-2100



Source: UN Population Statistics and Projections.

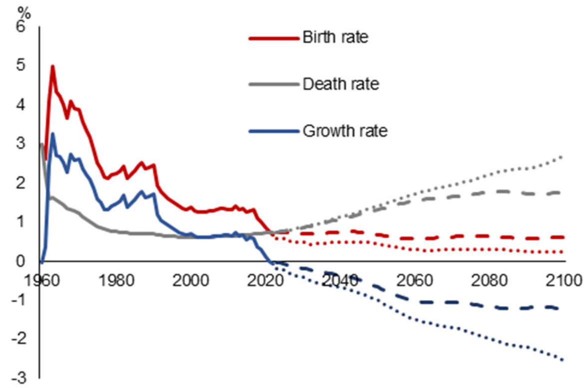
Figure 2. Life Expectancy of China, 1960-2100



Source: UN Population Statistics and Projections.

Figure 3 illustrates the historical and projected evolution of birth, death, and growth rates of China's population. Over the past sixty years, China's birth rate has declined from its peak of 5 percent in 1963 to 0.68 percent in 2022. Looking forward, even assuming a modest recovery in fertility rate, the birth rate is projected to continue to drop in the coming decades. Moreover, despite rising life expectance, the death rate is projected to increase rapidly as the population ages. Consequently, total population is expected to shrink significantly. Population growth rate is projected to decline from -0.06 percent in 2022 to -0.7 percent by 2050 and -1.2 percent by 2100, while the low variant scenario suggests an even sharper population decline.

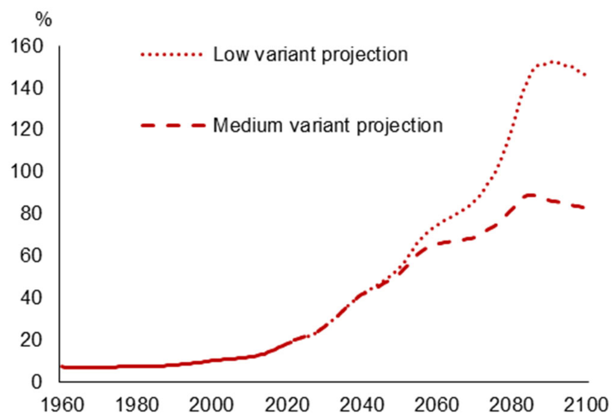
Figure 3. Birth, Death and Growth Rates of China's Population, 1960-2100



Source: UN Population Statistics and Projections.
* The dashed line represents medium variant fertility projection and the dotted line represents low variant fertility projection.

With the long-term decline in fertility and mortality rate, population aging will become increasingly pronounced. Under the UN's medium variant projection, the proportion of working-age population decreased from its peak of 74.5 percent in 2010 to 68.1 percent in 2022, while the elderly population aged 65 or above increased from 8.9 percent to 14.9 percent of total population in the same period. Over the same period, old-age dependency ratio, i.e., the ratio of the population aged 65 or over to the working-age population (aged 15–64), climbed from 11.9 percent to 21.9 percent, contributing more than two-thirds of the rise of the total dependency ratio. The UN population projections expect China's old-age dependency ratio to continue its rapid rise over the next six decades, reaching its peak between 2085 and 2090 at around 90 percent under the medium variant scenario and 150 percent under low variant scenario (Figure 4).

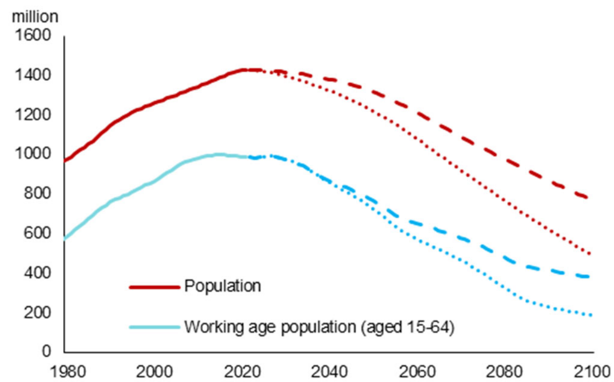
Figure 4. Old Age Dependency Ratio of China, 1960-2100



Source: UN Population Statistics and Projections.

The significant decline in China's labor supply amid population aging is striking. According to the UN's medium variant projection, China's total population is expected to decrease by 7.5 percent from 2020 to 2050 and by 45.8 percent by 2100. However, the reduction in the working-age population is even more pronounced, with a projected decrease of 22.3 percent by 2050 and 61.8 percent by 2100 (Figure 5). The low variant projection predicts a much sharper decline in the working-age population over the long term, with reductions of 26.4 percent by 2050 and 80.8 percent by 2100.

Figure 5. Population and Working Age Population of China, 1960-2100



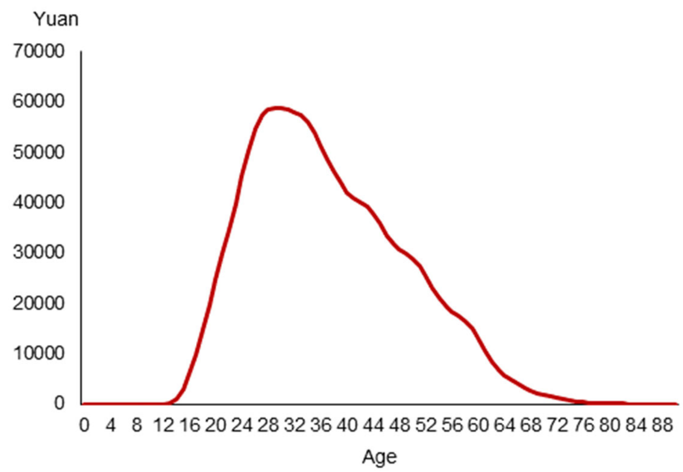
Source: UN Population Statistics and Projections.
* The dashed line represents medium variant fertility projection and the dotted line represents low variant fertility projection.

III. A Dynamic OLG General Equilibrium Model

To investigate the impacts of China's demographic transition on macroeconomic variables, we have developed a general equilibrium life-cycle model featuring a realistic demographic structure. The model divides the world economy into two regions - China and the rest of world. Each region is populated by 70 generations with variable life spans. The agents raise children and supply labor inelastically. They are rational, forward-looking and face no liquidity constraints. In addition to intended bequest, agents leave unintended bequest due to mortality risk and imperfect annuity markets. A representative, perfectly competitive firm in each country produces output using labor and capital. Installing new capital is assumed to be costly, and the investment behavior is described by Tobin's q-theory. Final demand is allocation between domestic and imported goods using the Armington (1969) assumption. Capital is fully mobile internationally, and exchange rates and interest rates are jointly determined by the interest parity condition. A stylized pay-as-you-go (PAYG) pension plan is incorporated into the model to reflect the actual pension schemes in both China and the rest of the world. The model is calibrated to the economic and population data of 2020 and runs from 2020 to 2300 to ensure reaching a steady state.

A key channel through which the population changes affect the economy in this model is the age profile of individual's labor earnings and savings. Age-earning profiles are typically hump-shaped, reflecting changes in labor force participation and relative productivity over the life cycle. Because of the individual's desire to smooth consumption over its lifetime, the age-saving profiles are also often hump-shaped: young agents save little in anticipation of rising future income, but progressively increase their savings as they age and decrease when retirement approaches. In China, the age-earning profile is heavily skewed toward younger ages with peak at age 30, as the young people with rising amounts of education disproportionately benefit from the urban-based, high-pay job opportunities brought by economic growth (Figures 6) (Lee, 2019). Contrary to the predictions of standard life-cycle theory, China's urban households exhibit a U-shaped age-saving profile, where the saving rates are higher for younger and older households.[5] Following Curtis, Lugauer and Mark (2015), we introduce a variation of the Barro and Becker (1989) preference in which parents derive their utility from both own consumption and their children's consumption into our OLG model. This specification enables the model to replicate a U-shaped saving pattern throughout individuals' working lives, as reflected in China's data.

Figure 6. Labor Income by Age, China, 2014



Source: National Transfer Accounts database. www.ntaccounts.org.

A. Structure of the model

In the model the long-term steady state rate of output growth is exogenous at rate g, which is driven by labor-augmenting technological change. Long-term population growth is assumed to be zero. For a clear separation of endogenous dynamic from exogenous trend, the model specification is simplified by detrending all variables into stationary variables through division by the quantities of efficiency units of population. For notational simplicity, the time subscript t and region subscript s are omitted in what follows if this does not lead to confusion.

(1) Households

The modeling of household behavior follows the life-cycle approach. Agents are born at age 1 and live a maximum of 70 years, corresponding to adult ages from 20 through 89. The probability of surviving between age j and age *j*+1 is denoted by s_j. All agents have identical preference over consumption, which are represented by the following utility function:

$$\sum_{j=1}^{70} \beta^j \left(\prod_{i=1}^{j} s_i \right) u\left(c_{j,} c_j^c, b\right) \tag{1}$$

[5] The U-shaped age-saving relation in urban China was empirically documented in Chamon and Prasad (2010) and Song and Yang (2010). Possible explanations for this abnormal saving pattern include precautionary savings (Chamon and Prasad, 2010; Chamon, Liu and Prasad, 2013), housing market (Bussière et al., 2013), effects of demographic structure and one-child policy (Curtis, Lugauer and Mark, 2015; Ge, Yang and Zhang, 2018; Choukhmane, Coeurdacier and Jin, 2023), bequest (Almås, Freddi and Thøgersen, 2020), and marriage squeeze (Nie, 2020).

where β is the subject discount rate. The period utility function $u(c_{j,}c_j^c, b)$ takes a Barro and Becker (1989) functional form which is additively separable among consumption of parents, c_j , consumption of children, c_j^c and bequest, *b*:

$$u(c_j, c_j^c, b) = \frac{c_j^{1-\gamma} + \rho_j^{-\gamma} b_j^{1-\gamma}}{(1-\gamma)} + \mu (n_j^c)^{\eta} \frac{(c_j^c)^{1-\gamma}}{(1-\gamma)}, \qquad \begin{array}{ll} \rho_j = 0, & \forall j \in \{1, \cdots, 69\}; \\ \rho_j = 1.5, & j = 70 \end{array} \qquad (2)$$

where γ is the coefficient of relative risk aversion and $1/\gamma$ is the intertemporal elasticity of substitution. ρ is the preference parameter for intended bequest. $\mu < 1$ and $\eta < 1$ determine the degree to which parents care for their children. n_j^c is the cohort-specific number of dependent children expressed on a per person basis. It is determined by a constant fertility profile by age and the time-variant total fertility rates.

The agent maximizes (1) subject to the following sequence of period budget constraints for each age j = 1, …, 70:

$$\begin{aligned} PC \cdot (c_j + n_j c_j^c) + (1+g) a_{j+1} \quad &= (1 - \tau_n - \tau_p) l_j \varepsilon_j w + z + B_j \\ &\quad + (1+r)(a_j + b^u + b) \end{aligned} \qquad (3)$$

together with $c_j \geq 0$, $c_j^c \geq 0$, and $a_{j+1} \geq 0$ if *j*=70. In (3) resources are derived from asset holdings a_j, labor endowment l, a lump-sum transfer *z*, pension benefits *B* for pensioners, an unintended bequest b^u and an intended bequest *b*. Assets pay an interest rate *r*. Labor receives a real wage $w \cdot \varepsilon_j$ and is taxed at labor income tax rate τ_n and payroll tax rate τ_p, where the efficiency parameter ε_j reflects the efficiency difference across age. In the absence of annuity markets, assets of individuals who die in each period are assumed to be distributed to all living individuals as lump sum transfer b^u. Expenditures on the left-hand side of equation (3) include purchase of consumption goods and acquisition of assets for the next period. *PC* is the tax-inclusive consumer price. There are no liquidity constraints, so the assets in (3) can be negative, although the terminal wealth must be non-negative if the agents survive up to terminal period (*j*=70).

(2) Firms and Technology

Production technology is characterized by a Cobb-Douglas function with two private factors of production (aggregate labor *L* and private capital K_p) and public capital, K_g:

$$Y = A K_p^{\kappa} L^{\theta} K_g^{1-\kappa-\theta}, \qquad 0 < \theta < 1, \qquad 0 < \kappa < 1, \kappa + \theta < 1 \qquad (4)$$

where *Y* is gross output and *A* is total factor productivity. κ and θ represent share parameters of private capital and labor in output, respectively.

In each period, the firm decides on the intensities of labor input, taking as given price of labor and the current stock of public and private capital, to minimize their cost. Thus, the firm employs factors according to marginal productivity rules.

$$R = \kappa A K_p^{\kappa-1} L^{\theta} K_g^{1-\kappa-\theta} \qquad (5)$$

$$w = \theta A K_p^{\kappa} L^{\theta-1} K_g^{1-\kappa-\theta} \tag{6}$$

where *R* is marginal product of private capital and *w* is the wage rate. As the production function exhibits decreasing returns to sale for private inputs, the firm earns a profit, *Π*, equal to the return to public capital.

$$\Pi = (1-\kappa-\theta)\cdot Y \cdot P \tag{7}$$

where *P* is the price of the goods.

The firm alters its private capital stock through investment I_p to maximize the value of firm, *V*, defined as the present value of net cash flow. By assuming a quadratic and homogenous adjustment cost function, the investment expenditure J_p, can be defined as:

$$J_p = \left[1 + \frac{\psi}{2}\frac{I_p}{K_p}\right]\cdot I_p \cdot PA \tag{8}$$

where *PA* is the price of composite goods and reflects the replacement cost of capital. The dynamic optimization problem of firms leads to the following two arbitrage conditions: (i) marginal cost of new investment is equal to the shadow price of installed capital, i.e. Tobin's *q*:

$$\partial(J_p)/\partial(I_p) = q, \quad i.e. \quad \frac{I_p}{K_p} = \frac{1}{\psi}\left(\frac{q}{PA} - 1\right) \tag{9}$$

and (ii) returns to financial and real investment are identical:

$$\begin{aligned} r_t q_{t-1} \quad &= \quad (1-\tau_k)\left(R_t + \frac{\Pi_t}{K_{p,t}}\right) + \tau_k \cdot \delta \cdot PA_t \\ &+ \quad \frac{\psi}{2}\left(\frac{I_{p,t}}{K_{p,t}}\right)^2 \cdot PA_t + (1-\delta)q_t - q_{t-1} \end{aligned} \tag{10}$$

where *δ* is the depreciation rate of capital and τ_k is the corporate income tax rate. The right-hand side of (10) defines the total return to capital, including the after-tax marginal product and capital gains.

(3) Government

The model specifies a general national government. At each period, the government purchases of goods and services, *G*, and public investment in infrastructure, J_g are financed through tax revenue and debt issuance, *D*. The government budget constraint at period *t* is:

$$\begin{aligned} G_t + J_g + z_t \cdot N + (1+r_t)D_t \quad &= \quad \tau_k(R_t - \delta \cdot PA_t)K_{p,t} + \tau_k \Pi_t + \tau_m PM_t M_t \\ &+ \quad \tau_n w_t L_t + \tau_c PA_t(C_t + G_t) + (1+g)D_{t+1} \end{aligned} \tag{11}$$

The left-hand side of equation (11) represents uses of government revenue, where *N*= $\sum_{j=1}^{70} n_j$ is the number of total population. Government purchases *G* are assumed to be unproductive and generate no utility to households. Government revenue in the right-hand side of equation (11) includes corporate income tax, labor income tax, consumption tax, tariff for imports *M*, and newly issued debt. Corporate income tax is levied on the profits of firms net of depreciation. *PM* is the import price.

The public investment is also assumed to entail adjustment costs similar to (8).

$$J_g = \left[1 + \frac{\psi}{2}\frac{I_g}{K_g}\right] \cdot I_g \cdot PA \tag{12}$$

Government also faces no-Ponzi-game constraint, i.e., $lim_{T\to\infty}(D_T/\prod_t^T(1+r_t)) \leq 0$, implying that the present value of government expenditure must be less than or equal to the present value of revenue plus the initial stock of government debt. To ensure the intertemporal budget constraint holds, we fix the ratio of *G* and *D* to GDP throughout the transition period and let the personal income tax rate or lump-sum transfer to the households endogenous to balance the period budget.

(4) Social Security

There is a simple PAYG system in this model. Individuals start to receive pension benefits after retirement, which are financed by payroll tax. The pension scheme is independent of the government's regular budget and needs to satisfy its own intertemporal budget constraints. The total pension contribution, *S* is defined as:

$$S = \tau_p wL \tag{13}$$

The pension benefits for generations older than retirement age, B is defined as:

$$B_j = \vartheta_j \cdot AVE_j, \quad j > \Upsilon_j \tag{14}$$

whereϑ_j is the generation-specific replacement ratio and Υ_j is the age of retirement for generation *j*. The average of earning over the working time, AVE_j is defined as:

$$AVE_{j,t} = \sum_{k=1}^{\Upsilon_j} l_{j,t-(j-k)}\varepsilon_j w_{t-(j-k)} \Big/ \Upsilon_{j,t}\,, \qquad j > \Upsilon_{j,t} \tag{15}$$

The pension scheme is assumed to be self-financing and maintain balanced budget annually, i.e.:

$$S = \sum_{j=1}^{70} B_j n_j \tag{16}$$

The payroll tax rate τ_p adjusts endogenously each year to satisfy the budget constraint of the scheme.

(5) Foreign Trade and International Payment

Demands are for composites of foreign and domestic goods. A CES function is utilized to specify the aggregation of composite goods, implying that products are differentiated by region of origin, i.e. the Armington assumption (Armington, 1969).

$$C + G + (J_p + J_g)/PA = \left[(1-\alpha^m)(Y-X)^{(\sigma-1)/\sigma} + \alpha^m (M)^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)} \quad (17)$$

where C denotes the aggregate consumption and *X* denotes exports.

The corresponding price index *PA* is the combination of the price of imports, *PM* and the producer price of domestic good, *P*. It is specified as a unit cost function.

$$PA = [\alpha_m^{\sigma}(PM)^{1-\sigma} + (1-\alpha_m)^{\sigma}(P)^{1-\sigma}]^{1/(1-\sigma)} \quad (18)$$

Import price of region s, PM_s is determined by region *s*'s exchange rate, ER_s, import tariff and the producer price of its trading partner, P^*.

$$PM_s = P^* \cdot ER_s(1+\tau_{m,s}) \quad (19)$$

Exchange rate ER is determined by an adjusted uncovered interest rate parity condition.

$$(1+r_{t+1}) = (1-\Gamma_{t+1})(1+r_{t+1}^*) \cdot \frac{ER_{t+1}}{ER_t} \quad (20)$$

where r^* is foreign interest rate and Γ is the transaction fee for foreign borrowing or lending. The transaction cost is a function of the average net asset position of the whole economy, following the IMF's Global Economic Model (GEM) (Pesenti, 2008):

$$1-\Gamma = \left(1-\varphi^{b1}\frac{exp\left(\varphi^{b2}[ER \cdot F/GDP - fss]\right)-1}{exp(\varphi^{b2}[ER \cdot F/GDP - fss])+1}\right)\frac{\beta^*}{\beta} \quad (21)$$

where F indicates net foreign asset and *fss* is the desired net foreign asset positions expressed as a ratio of GDP. φ^{b1} and φ^{b2} are parameters with 0< φ^{b1} <1 and φ^{b2}>0.

(6) Aggregation

Total consumption equals the sum of consumption by each cohort:

$$\sum_{j=1}^{70}\{n_j(n_j^c c_j^c + c_j)\} = C \quad (22)$$

Aggregate labor input is given by:

$$\sum_{j=1}^{70}\varepsilon_j l_j n_j = L \quad (23)$$

The clearing condition in the capital market requires that total national wealth, including total private wealth and government net wealth, equals the value of domestic firms plus net foreign asset, denominated in U.S. dollar.

$$\sum_{j=1}^{70} a_j n_j - D = ER \cdot F + V \tag{24}$$

Net foreign asset F is determined by current account balance and subjects to the following clearing condition:

$$F_{chn} + F_{row} = 0 \tag{25}$$

(7) Equilibrium

For a given government policy $\left\{G_t, D_t, J_{g,t}, \tau_n, \tau_k, \tau_m, \tau_c, \vartheta_j\right\}_{t=0}^{\infty}$ and $\{K_{p,0}, K_{g,0}, F_0\}$, the model's dynamic competitive equilibrium is the sequences of price $\{w_t, R_t, ER_t, r_t, q_t, P_t, PA_t, PC_t, PM_t\}_{t=0}^{\infty}$ and allocations $\left\{b_t, b_t^u, c_t, c_t^c, K_{p,t+1}, K_{g,t+1}, Y_t, \Pi_t, C_t, J_{p,t}, I_{p,t}, I_{g,t}, X_t, M_t, F_{t+1}, z_t, S_t, B_t, \tau_{p,t}\right\}_{t=0}^{\infty}$ for each region such that:

(1) The allocation solves the dynamic program (1)-(3) for all agents, given the prices and government policy.

(2) The allocation satisfies (5) – (10) to maximize the profits of firms.

(3) The allocation and government policy satisfy the budget constraint of the pension scheme given the prices.

(4) The allocation and payroll tax rate satisfy the budget constraint of the pension scheme (16) given the prices.

(5) M_t satisfies the first order conditions of the optimization problems of minimizing the costs of composite goods.

(6) Capital and labor markets clear, that is (23) and (24) satisfied.

(7) Unintended bequests equal lump sum transfers b^u.

B. Model calibration

The calibration of a dynamic model, under the assumption of perfect foresight, involves identifying a dataset that covers all periods of the model and is consistent with the intra-period and intertemporal equilibria. This dataset must not only replicate the data of the base year but also serves as the dynamic benchmark equilibrium for the model. The dynamic calibration assumes that the economy in the base year is in a temporary equilibrium along a dynamic adjustment path. This approach is particularly suitable for fast-growing economies, such as China, as opposed to assuming a stationary steady state.

The model is calibrated to macro and population data of 2020. Most elasticity parameters and dynamic adjustment parameters are derived from existing literature on dynamic models in determining their values. Table 1 summarizes the major parameters of the model.

Table 1. Benchmark parameters of the model

	Definition	Value
$1/\gamma$	Intertemporal elasticity of substitution	0.50
β	Households subjective discount rate	1.012*
ρ	Preference parameter for intended bequest	1.5
μ	Weight on children	0.58
η	Concavity for children	0.76
σ	Elasticity of substitution between imports and domestic goods	2.50
δ	Depreciation rate of physical capital	0.06
ψ	Capital adjustment cost parameter	2.00
φ^{b1}	Parameter governing short-run dynamics of net foreign assets	0.10
φ^{b2}	Parameter governing short-run dynamics of net foreign assets	0.20
$g-1$	Long-term growth rate of the global economy	0.02

Source: Authors' assumptions on the basis of existing similar studies.
*The subjective discount rate is set to generate the targeted long-term interest rate of 4.2 percent.

In calibrating the household sector, the value of the intertemporal elasticity of substitution is set at 0.5 (γ=2), which is close to the upper end of the range of empirical estimates. The time preference parameter β is chosen to generate a steady-state real interest rate of 4.2 percent. This value of 1.012 is high, but individuals also effectively discount the future due to the incorporation of survival probabilities s. The parameters characterizing the weight parents put on utility from children's consumption, μ and η, are taken from Curtis, Lugauer and Mark (2015). The age profile of fertility is also taken from Curtis, Lugauer and Mark (2015). The age-specific labor endowment ε is calculated based on the life-cycle labor income profile obtained from the National Transfer Accounts (NTA) project.

The output shares of public capital, $1-\kappa-\theta$, is 0.14 for the world and 0.07 for China (Arslanalp et al., 2010; World Bank, 2017). The output share of capital and labor, κ and θ, are calculated from the base year national account data. The value of capital adjustment cost parameters is taken as 2, which corresponds to the low end of some empirical estimates. The depreciation rate of physical capital is set at 6 percent per year. Following the literature of trade models, the elasticity of substitution between imports and domestic goods, i.e., the Armington elasticity, is set to be 2.5. All tax rates, including payroll tax rates, are calibrated from the base year tax and pension revenues.

IV. Model Simulations

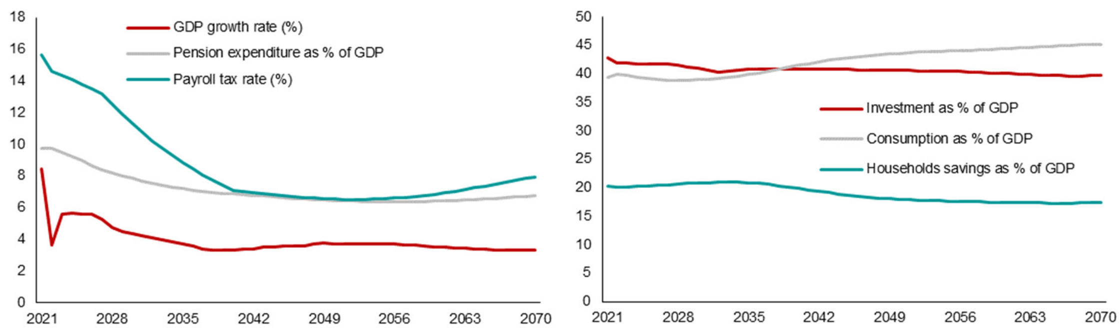
A. Impacts of the Population Transition

To quantify the impacts of the future population changes, we first establish a counterfactual reference scenario in which population in China is assumed to be stationary. Specifically, the reference scenario assumes that the death rate is constant at its 2020 level and the death rate is equal to the birth rate. Then the population projections of the UN medium variant and low variant are introduced as the demographic shocks. The differences between the two demographic shock scenarios and the reference scenario reveals the effects of demographic transitions in China.

Figure 7 presented the change of GDP growth and other major macro-economic variables for China over 2020-2070 under the reference scenario. Because of the assumed deceleration in productivity growth, China's GDP growth slows from current rate of around

5.5 percent to an average of 3.7 percent in the 2030s and 3.5 percent in the 2040s in the reference scenario. The investment-to-GDP ratio declines slightly from 42 percent in 2021 to 40 percent after 2060, while the household consumption-to-GDP ratio increases from less than 40 percent in the 2020s to 45 percent by 2070. Correspondingly, household savings as a percentage of GDP decline slightly from 20 percent in 2021 to 17.5 percent in 2070. As China's GDP maintains a fast growth in the first two decades of the model simulation period, while its population and number of pensioners remain stable in the reference scenario, pension expenditure as a percentage of GDP decline in 2021-2040. Consequently, the required payroll tax rate to balance the PAYG pension scheme also declines in this period.

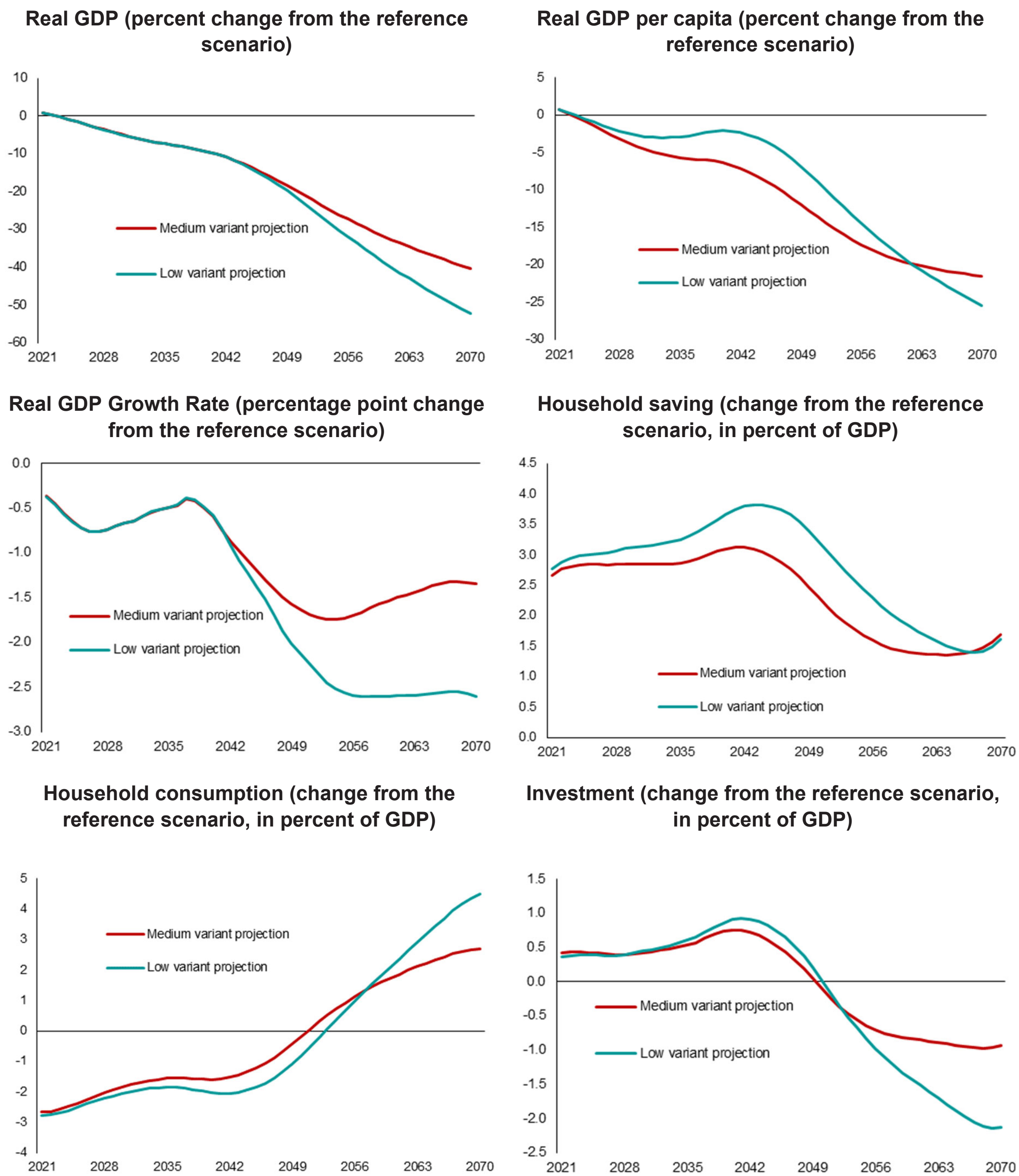
Figure 7. Macroeconomic Results of the Reference Scenario for China



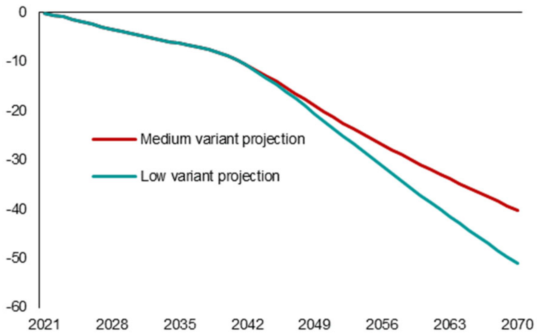
Source: Model simulations.

The impacts of China's demographic changes on its macroeconomy are summarized in Figure 8, which present the simulation results as deviations from the reference scenario. Compared to the baseline of stationary population, the GDP level in 2070 is estimated to decrease cumulatively by 40.5 percent under the scenario of medium variant projection and 52.4 percent under the scenario of low variant projection. Per capita GDP also declines, as the productivity-adjusted effective labor supply falls by more than the population. Due to differences in labor productivity across age cohorts, the aging of the labor force will lead to a larger decline in labor measured in efficiency unit. In growth terms, demographic changes projected by the UN's medium variant scenario will reduce China's annual growth of GDP and per capita GDP by 1.09 and 0.86 percentage points, respectively, from 2021 to 2070 compared to the baseline. Under the low variant scenario, the deceleration in the growth of GDP and per capita GDP is even greater, at 1.40 and 1.05 percent, respectively. Nevertheless, the adverse impacts of the low variant scenario compared to the medium variant scenario become significantly noticeable only after 2040, owing to the delayed impact of declining fertility rates on the labor force.

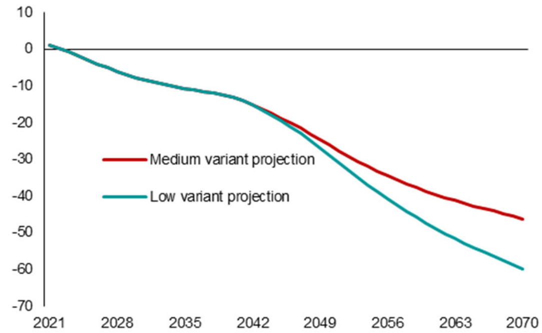
Figure 8. Macroeconomic Effects of China's Population Shifts for China



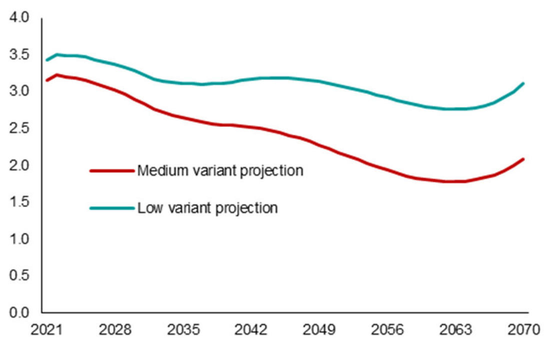
Labor force (percent change from the reference scenario)



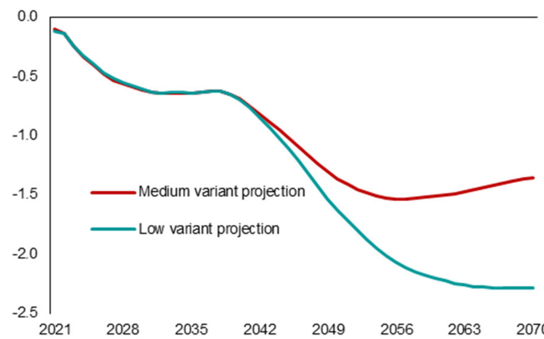
Effective labor force (percent change from the reference scenario)



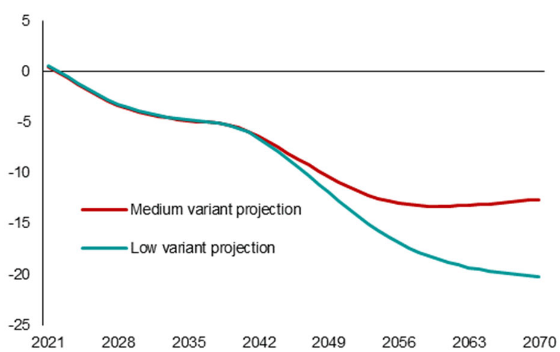
Current account balance (change from the reference scenario, in percent of GDP)



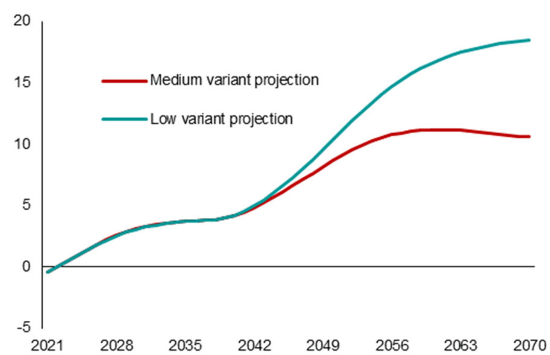
Interest rate (percentage point change from the reference scenario)



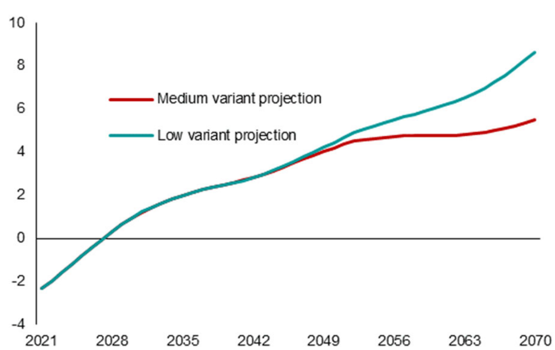
Rental rate to capital (percent change from the reference scenario)



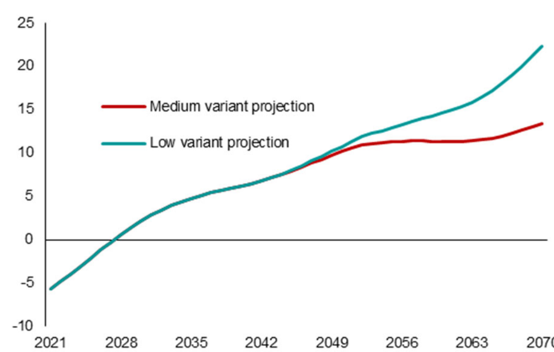
Pre-tax wage rate (percent change from the reference scenario)



Pension expenditure (change from the reference scenario, in percent of GDP)



Pension payroll tax rate (percentage point change from the reference scenario)



Source: Model simulations.

The severity of demographic shocks on China's economic growth will vary over time. As post-famine baby boomers reach the age of 65 and above, China's aging will accelerate, resulting in a reduction of about 0.75 percentage points in annual growth in the period of 2026 to 2028. Subsequently, as fewer people enter retirement age, this growth deceleration caused by demographic transition will moderate in the 2030s. However, GDP growth is likely to deteriorate notably after 2040 as the continuous reduction in new, young workforce entrants leads to a rapid decline in labor supply. By 2050, demographic shifts could lower China's growth rate by as much as 1.64 percentage points in the medium variant scenario and 2.13 percentage points in the low variant scenario. Following 2055, the growth deceleration is projected to be more moderate under the medium variant scenario, but remain above 2.5 percentage points under the low variant scenario.

Despite the higher proportion of elderly people amid the demographic transition, household savings as a ratio to GDP would increase by an average of 2.9 percentage points during 2021-2040 in the medium variant scenario and 3.2 percentage points in the low variant scenario. Two reasons accounts for the uptick of saving rate in the initial stage of population transition. First, lower fertility reduces spending on the consumption of children. Secondly, the anticipated longer time in retirement due to increased longevity effectively lowers households' discount rates. The rise in savings translates into reduced consumption spending, which is expected to decline by an average of 2.0 percentage points and 2.2 percentage points as a ratio to GDP during the same period under the two alternative population projections.

With more and more individuals entering retirement, the share of retired dissavers within the population increase, exacerbating the negative impact of population aging on household savings. The simulation results indicate that the demographic-induced increases in the household saving rate will taper off after 2045, decreasing to less than one percentage point by 2060. Consequently, in comparison to the baseline scenario, the ratio of household consumption to GDP is expected to rise after 2050-55 under the two scenarios of UN population projection. The increase in savings also exerts downward pressure on interest rates. The decrease in China's interest rate is projected to widen from 0.1 percentage point in 2020 to 0.6 percentage point in 2030, stabilizing thereafter until 2040. Beyond 2040, the rapid decline in the influx of young workers will further depress both economic growth and interest rate. [6]

A lower interest rate relative to the rest of the world spurs outflows of capital. As a result, China's current account balance to GDP ratio is estimated to be 2.4 percentage points higher on average during 2020–2070 under the medium variant scenario and 3.0 percentage points higher under the medium variant scenario when compared to the reference scenario.

Two offsetting forces determines the impacts of demographic changes on investment. As the labor force decline, the capital-labor ratio rises, causing a decrease in the return to capital relative to the return to labor. Consequently, this reduces firms' incentives to invest. On the other hand, declining interest rate encourages investment by lowering its costs. The simulation results suggest that investment as a share of GDP would increase between 2020

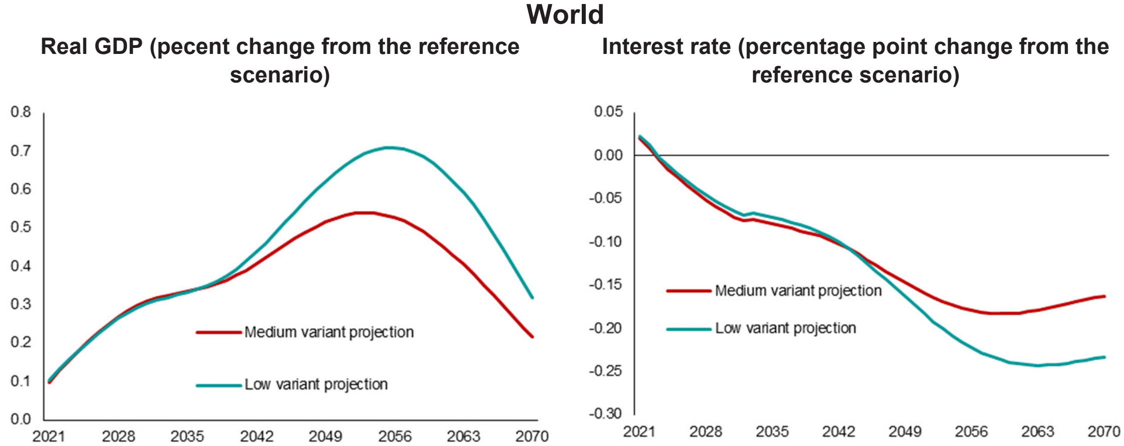
[6] This finding on real interest rate contrasts with the arguments in Goodhart and Pradhan (2017) but is consistent with research findings of Kruger and Ludwig (2007), Carvalho, Ferrero and Nechio (2016), and Aucler et al. (2021), among others.

and 2050,but decline thereafter. As the effects to declining labor force continue to unfold, the return of capital would fall more sharply after 2042, gradually dominating the impacts of the lower interest rates.

Population aging is expected to impose a significant pension burden for China. Compared to the reference scenario, pension expenditure as a percentage of GDP in 2070 is projected to expand by 5.5 percentage points under the medium variant scenario and 8.6 percentage points under the low variant scenario. This increase would necessitate additional government financing—for example, by raising taxes or issuing more bonds—to fill the resulting gap. Under a defined-benefit PAYG scheme, the contribution rate for the current generation of workers in 2070 would need to be hiked by 13.4 percentage points and 22.3 percentage points, respectively, to balance the pension fund.

China's population changes will impact the rest of the world primarily through the channel of capital flows. The outflow of China's savings driven by demographic effects, which is projected to be 2 to 3 percent of China's GDP, is expected to depress the global interest rate by 0.15-0.25 percentage points in the 2060s (Figure 9). These augmented capital inflows and reduced interest rates would boost investment and stimulate economic growth in the rest of world, albeit only to a modest extent.

Figure 9. Macroeconomic Effects of China's Population Shifts for the Rest of the World



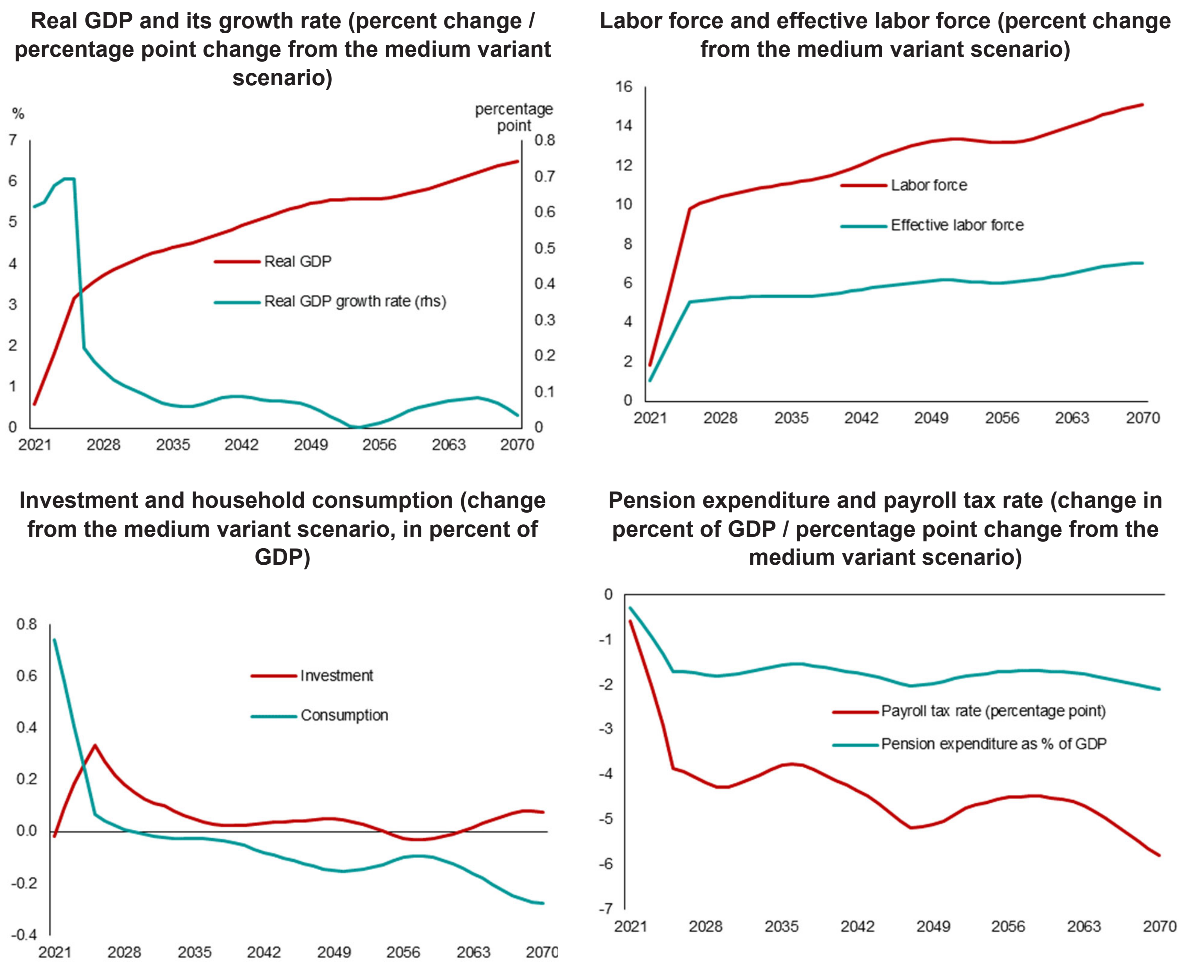
Source: Model simulations.

B. Impacts of Raising Retirement Age

Formulated in 1950s, China's current retirement policy features some of the world's lowest retirement ages: 50 years for female blue-collar workers, 55 years for female office workers, and 60 years for men. With life expectancy increasing significantly, raising the retirement age has emerged as a viable policy solution to address China's aging population issue. To examine the potential implications of such a policy reform, this sub-section simulates a scenario in which the policy shock of retirement age change is added to the scenario of the medium variant population projection. Specifically, the policy shock assumes a gradual increase of 5 years in the retirement age in China over the period of 2021-2025.

Figure 10 presents the major simulation results of this scenario. Postponing the retirement age by five years would increase the labor supply, which is projected to surge by 9.8 percent in 2025 and by 15.1 percent in 2070. As the new entrants to the labor force are older with lower productivity, the rise in effective labor is more modest, amounting to approximately half of the increase in the labor force. The annual average growth rate of real GDP would be raised by 0.66 percentage point in the initial five years of raising retirement age, but this gain would be gradually diminished to 0.04 percentage point over the long term. In anticipation of higher lifetime income, young generations of workers increase their current consumption expenditure, leading to an increase in the consumption share of GDP in initial years. However, this trend is projected to wane over time. The postponement of the retirement age essentially redistributes income from pensioners to workers who pay lower payroll taxes. As pensioners have higher marginal propensity to consumption, the overall household consumption as a percentage of GDP would decline modestly in the long run. The reform will help improve the sustainability of the PAYG pension system. Over the long run, total pension expenditure as a percentage of GDP is expected to decrease by 2.1 percentage points and the payroll tax rate would be reduced by 5.8 percentage points. However, these adjustments only partially offset the impacts of expected demographic shifts in China.

Figure 10. Macroeconomic Effects of Raising Retirement Age for China



Source: Model simulations.

V. Conclusions

This paper quantitatively explores the macroeconomic impact of China's population transition using a multi-region overlapping generations model. The simulations indicate that China's economic growth is likely to decelerate significantly due to demographic shifts over the coming decades. A shrinking workforce, coupled with an increasing proportion of elderly individuals, will place downward pressure on labor supply, consumption, and interest rates. Moreover, the strain on public finance is expected to intensify.

These findings underscore the urgency of implementing proactive structural reforms to counteract the adverse effects of population aging. One potential policy measure is raising the retirement age to boost labor supply and reduce the pension system's fiscal burden. However, the benefits of such a policy would be relatively modest in the face of the impending demographic challenges. Additionally, these reforms must be carefully designed to balance the needs of both current and future generations, considering their varied impacts across different age groups.

Broadly, enhancing the flexibility of labor markets and improving labor force participation rates, especially among older and female cohorts, could further mitigate these challenges. Investing in automation and digital technologies may also offset some of the declines in labor productivity associated with an aging workforce.

In addition, to further support economic growth and mitigate the impact of an aging population, policymakers should consider enhancing educational and training opportunities to increase productivity across all age groups. Fostering a lifelong learning environment can help older workers adapt to changing job requirements and extend their professional lives. Moreover, the government could incentivize businesses to hire and retain older workers through tax breaks and reduced payroll contributions.

It is also important to acknowledge the limitations of this study. The model assumes constant age-specific labor participation rates and does not account for labor-leisure choices that could affect labor supply dynamics. Introducing endogenous labor supply adjustments in response to wage and tax policy changes could provide a more accurate depiction of the labor market's response to demographic and policy shifts. Furthermore, the model simplifies the intricacies of China's pension system. A more detailed modeling of China's pension scheme, including its various tiers and private components, would improve the model's ability to simulate the effects of comprehensive social security reforms. These indicate directions for further research.

References

Almås, I., E. Freddi and Ø. Thøgersen. 2020. "Saving and Bequest in China: An Analysis of Intergenerational Exchange," *Economica*, vol. 87(345), pp 249-281, January.

Arslanalp S., F. Bornhorst, S. Gupta, and E. Sze. 2010, "Public Capital and Growth," IM Working Paper, WP/10/175

Auclert, A., H. Malmbergy, F. Martenetz and M. Rognlie. 2021. "Demographics, Wealth, and Global Imbalances in the Twenty-First Century," Working Paper

Auerbach, A. J., and L. J. Kotlikoff. 1987. *Dynamic Fiscal Policy*, Cambridge University Press

Auerbach, Alan J., Laurence J. Kotlikoff, Robert P. Hagemann and Guiseppe Nicoletti. 1989."The Economic Dynamics of an Ageing Population: the Case of Four OECD Countries," *OECD Economic Studies* no. 12.

Bussière, Matthieu, Yannick Kalantzis, Romain Lafarguette and Terry Sicular. 2013. "Understanding household savings in China: the role of the housing market and borrowing constraints," MPRA Paper 44611, University Library of Munich, Germany.

Carvalho, C, A Ferrero and F Nechio. 2016. "Demographics and real interest rates: Inspecting the mechanism", *European Economic Review* 88: 208-226

Chamon, Marcos D., and Eswar S. Prasad. 2010. "Why Are Saving Rates of Urban Households in China Rising?" *American Economic Journal: Macroeconomics* 2(1), pp. 93–130.

Chamon, Marcos D., Kai Liu, and Eswar S. Prasad. 2013. "Income uncertainty and household savings in China," *Journal of Development Economics* 105, pp. 164-177.

Choukhmane, Taha, Nicolas Coeurdacier and Keyu Jin. 2023. "The One-Child Policy and Household Saving," *Journal of the European Economic Association*, European Economic Association, vol. 21(3), pp. 987-1032.

Cheng, Kevin C. 2003. "Economic Implications of China's Demographics in the 21st Century," Working Paper No. 2003/29, International Monetary Fund

Curtis, Chadwick C., Steven Lugauer, and Nelson C. Mark. 2015. "Demographic patterns and household saving in China," *American Economic Journal: Macroeconomics* 7(2), pp. 58-94.

Ge, Suqin, Dennis Tao Yang, and Junsen Zhang. 2018. "Population Policies, Demographic Structural Changes, and the Chinese Household Saving Puzzle," *European Economic Review* 101(C), pp.181-209

Goodhart, C., and M. Pradhan. 2017. "Demographics Will Reverse Three Multi-decade Global Trends." BIS Working Paper No. 656.

He, Hui, Lei Ning, and Dongming Zhu, 2019. “The Impact of Rapid Aging and Pension Reform on Savings and the Labor Supply: The Case of China,” Working Paper No. 2019/61, International Monetary Fund

Kotlikoff, Laurence J., Kent Smetters, and Jan Walliser. 2007. “Mitigating America's demographic dilemma by pre-funding Social Security.” *Journal of Monetary Economics* 54(2): 247–266.

Krueger, Dirk and Alexander Ludwig. 2007. "On the consequences of demographic change for rates of returns to capital, and the distribution of wealth and welfare," *Journal of Monetary Economics*, Elsevier, vol. 54(1), pp 49-87

Kwon, Kyooho, 2017. “Korea's Demographic Transition and Long-Term Growth Projection Based on an Overlapping Generations Model,” *KDI Journal of Economic Policy*, 39(2), pp. 25-51

Lee, Roland. 2019. “Population Aging and Its Economic Consequences for the People’s Republic of China,” *ADB East Asia Working Paper Series*, No. 19, November 2019, Asian Development Bank

Li, Yue, Qian Wang and Xuying Zhang. 2023. “"Where is the Fertility Level Going: Backward Estimation and Trend Forecasting", Paper presented at the Annual Meeting of the Demographic Society of China（李月、王茜和张许颖 2023 “生育水平向何处去：回推估计及趋势预测”, 中国人口学会年会交流论文, 2023 年 7 月)

Miles, David., 1999. “Modelling the Impact of Demographic Change upon the Economy.” *The Economic Journal*, 109, 1-36.

Muto, I., T. Oda and N. Sudo. 2016. “Macroeconomic Impact of Population Aging in Japan: A Perspective from an Overlapping Generations Model,” *IMF Economic Review*, 64(3) pp. 408-442

Nie, Guangyu. 2020. “Marriage Squeeze, Marriage Age and the Household Savings Rate in China,” *Journal of Development Economics,* 147

Pesenti, P., 2008. “The Global Economy Model (GEM): Theoretical Framework”, *IMF Staff Papers*, 55(2)

Ríos-Rull, José-Víctor. 2001. “Population Changes and Capital Accumulation: The Aging of the Baby Boom,” *The B.E. Journal of Macroeconomics*, 1(1), pp. 1-48

Song, Zheng, and Dennis Tao Yang. 2010. “Life Cycle Earnings and Saving in a Fast-Growing Economy.” http://faculty.chicagobooth.edu/workshops/macro/past/pdf/101111.pdf.

Song, Z., K. Storesletten, Y. Wang, and F. Zilibotti. 2015. “Sharing High Growth Across Generations: Pensions and Demographic Transition in China,” *American Economic Journal: Macroeconomics*, 7(2): 1-39.

World Bank, 2017, *Global Economic Prospects*, January. Washington DC

Zhang, Junsen. 2017. “The Evolution of China’s One-Child Policy and Its Effects on Family Outcomes,” *Journal of Economic Perspectives* 31 (1):141–160

ASEAN +3 MACROECONOMIC RESEARCH OFFICE
Address: 10 Shenton Way, #15-08
MAS Building, Singapore 079117
Website: www.amro-asia.org
Tel: +65 6323 9844
Email: enquiry@amro-asia.org
LinkedIn | Twitter | Facebook | YouTube