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# Global Demographic Change and International Capital Flows: Theory and Empirics

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## Abstract

While population has been aging globally, regions and countries are significantly asymmetric in the timing and speed of the demographic transitions, especially between developed and developing regions. This paper explores the impacts of asymmetric demographic change on international capital flows with two contributions. First, the paper introduces demographic structure and pension systems into a theoretical overlapping-generation model of a small open economy, and derives an analytical solution which links a large set of factors to the current account. This framework enables tractable analysis of the effects of various demographic shocks on external balances, and also of the interaction between demographic shocks and productivity growth and pension systems. Second, the paper provides a comprehensive literature review of both modeling and empirical studies. There are several qualitative implications. First, the patterns of capital flows depend on the nature of demographic shocks (permanent or transitory; fertility or mortality) and also on the stage of demographic shocks. Second, less generous pension systems tend to increase national saving and drive capital outflows. Third, financial frictions such as borrowing constraints of young people tend to increase national saving and drive capital outflows. Fourth, production and trade specialization in labor-intensive sectors tends to decrease investment and drive capital outflows in the face of fertility growth. Fifth, the magnitude of the demographic effects depends on the extent of cross-border mobility of capital, labor and goods. There are also several quantitative implications. First, demographics alone can explain a significant fraction of historical current account dynamics among advanced economies, especially low-frequency movements. Second, institutional and financial frictions need to be incorporated to reconcile the demographic effects with historical capital flows from emerging to advanced economies. Third, production structure and trade specialization also play an important role in demographics-driven capital outflows from emerging economies. On the other hand, empirical studies strongly support that the demographic change since the second half of last century has statistically significant effects on the current account balance. The current account tends to decrease in the dependency ratio, and increase in the working-age population share. This paper also points out the potential research direction.

**Keywords**

Global demographic change, fertility and mortality, international capital flows, current account balances, overlapping generation model, pension systems, factor mobility, financial frictions, structural change

**JEL Classification**

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# Global Demographic Change and International Capital Flows: Theory and Empirics

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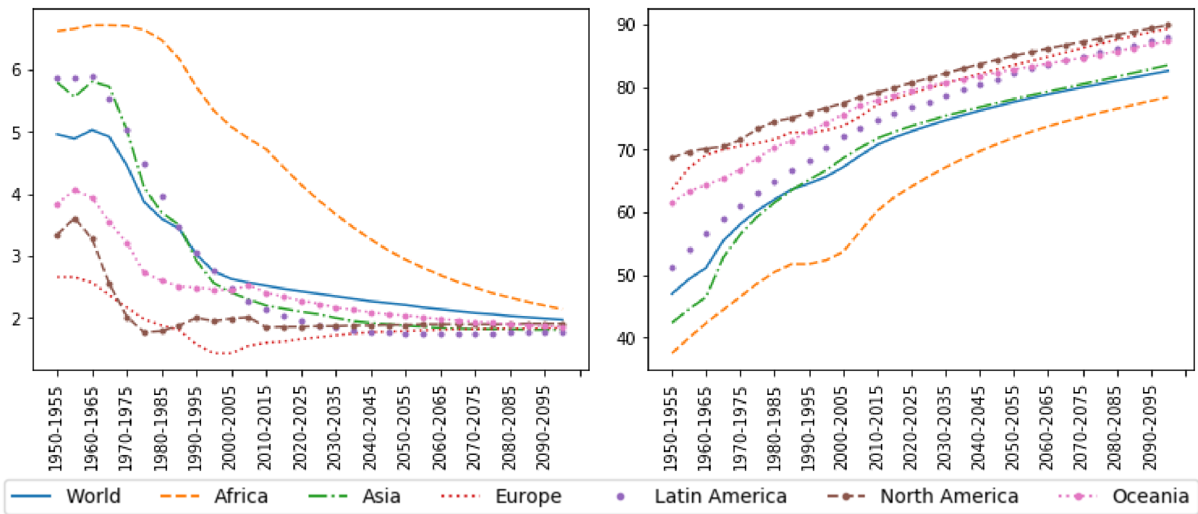
# 1 Introduction

The world has been experiencing dramatic demographic change after World War II, which has been driven by decreasing fertility and increasing longevity (or decreasing mortality) (Figure 1). Total fertility rate (the average number of children a woman would bear over her lifetime) fell from 5 children per woman in 1950 to 2.5 nowadays and is projected to fall even further in the next few decades. Life expectancy increased from 47 years in 1950 to over 65 nowadays and is projected to reach 83 years by 2100. While the world shares a similar long-run trend, regions and countries are significantly asymmetric in the timing and speed of the demographic transitions, particularly between developed and developing countries (see Bloom and Luca 2016 for an extensive overview). This asymmetry has significant impacts on the landscape of the world economy in the long run, and also has important cross-border economic implications.

Figure 1: Fertility rate and life expectancy by region

(a) Total fertility rate by region (b) Life expectancy by region



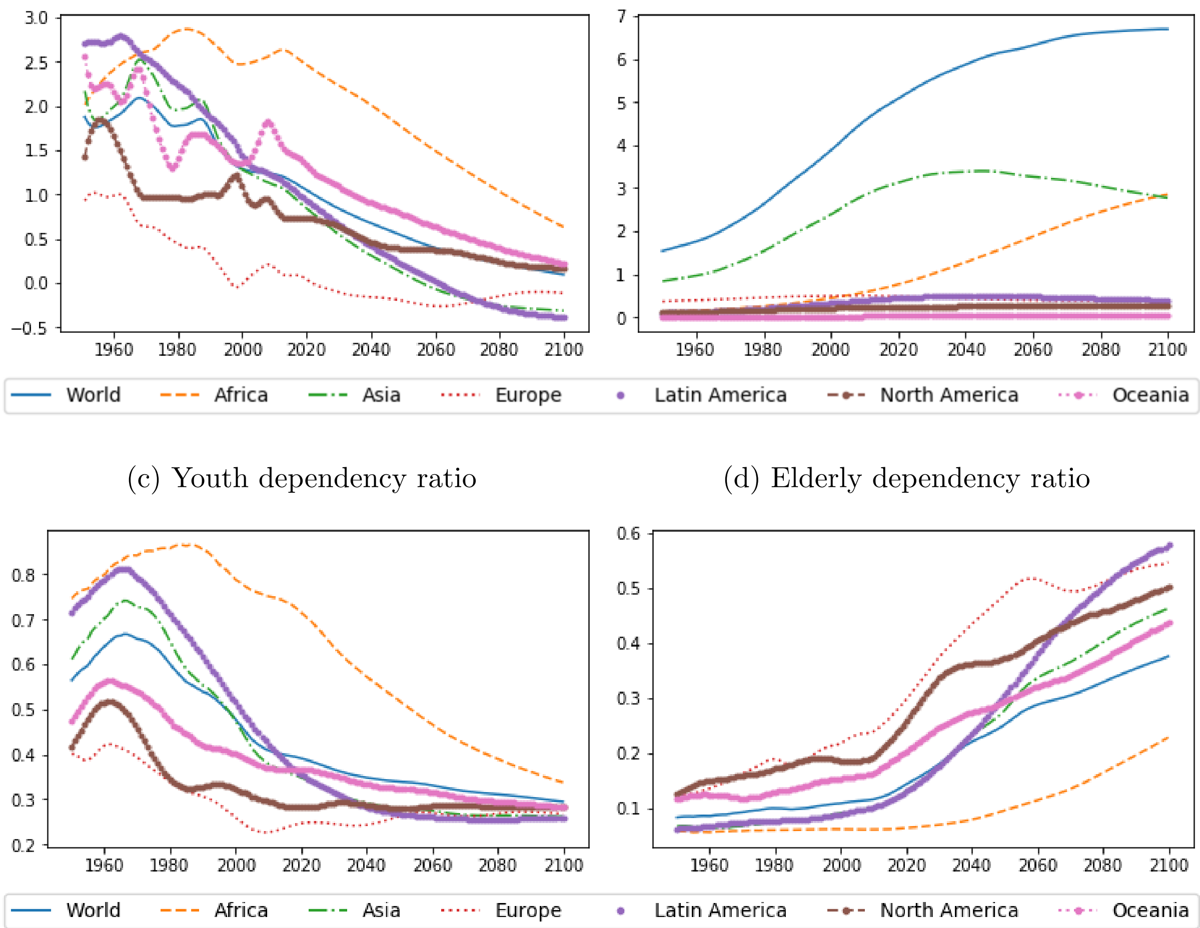

Due to fertility declines, population growth has slowed down all around the world and is expected to decline further over this century (Figure 2a). Global population rose at an annual rate close to 2 percent in the 1950s and reduced to an annual rate close to 1 percent in the 2010s. This trend is expected to continue with the growth rate declining to around 0.5 percent by 2050. There is also significant asymmetry across regions. Population growth has been much higher in developing countries, particularly in Africa and emerging Asia, than in advanced countries. European population growth has been much lower than the world average, and its growth rate is already close to zero. In contrast, Africa has been showing strong growth since 1950, with the growth rate still as high as 2.5 percent nowadays. In addition to population growth, population size, particularly working-age population, is a key driver of shaping the landscape of the world economy this century. Global working-age population will continue to increase fast until 2050, driven by Asia and Africa (Figure 2b). Asia's working-age population will increase until 2030 because of China and India, and is expected to plateau out in the following two decades and then to decline gradually. Africa will enjoy strong growth in the working-age population. More than half of the working-age population growth in the world will come from Africa over 2020-2050. Latin America will moderately increase until 2050, while Europe has already started to decline in 2011. North America and Oceania have been experiencing low but steady increases in the working-age population because of migration into the two regions.

The combination of declining fertility and increasing longevity has been substantially changing age structure. Population has been aging in most regions and is expected to age more rapidly in all regions in the next several decades. The youth dependency ratio (the ratio of population under 15 to population over 15-64) started to decline in the 1980s (Figure 2c), and the elderly dependency ratio (the ratio of population over 64 to population over 15-64) will increase fast over 2020-2050 (Figure 2d). This is mainly because the baby boom generations born in the two decades after World War II are currently retiring over the period of 2010-2030. The population aged 60 or over is prejected to rise from around 1 billion in 2020 to almost 2 billion by 2050, representing 22 percent of the world population. The proportion of individuals aged 80 or over is projected to rise from 1 to 4 percent of the global population over 2020-2050. There is also distinct asymmetry between countries and regions. Population aging has started in advanced economies, followed by developing countries with a sizable delay.

Figure 2: Population growth and dependency by region

(a) Population growth (%) (b) Working-age population (Billion)

(c) Youth dependency ratio (d) Elderly dependency ratio



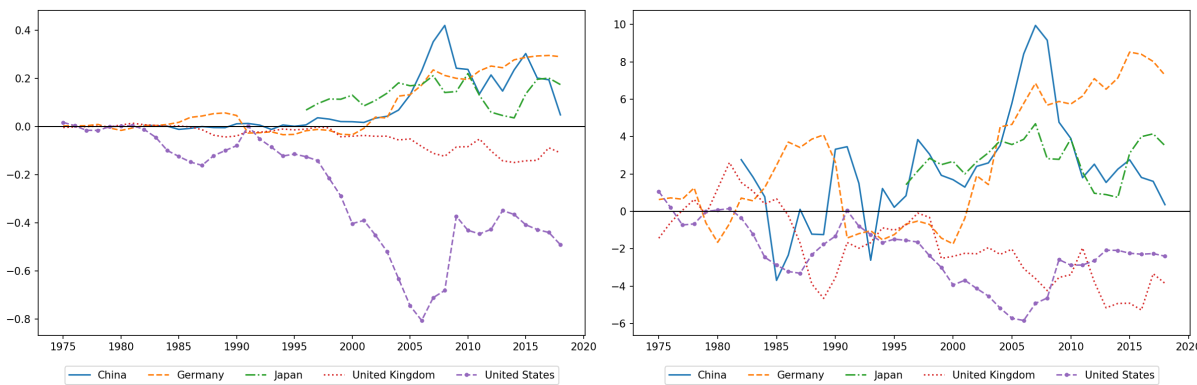

Demographic change has important long-run macroeconomic impacts through a number of channels including labor supply, consumption and saving, consumption patterns, infrastructure demand, government budgets, human capital, etc (Bryant and McKibbin 1998; Lee 2016). The literature often focuses on domestic demographic trends in developed economies, particularity on pension sustainability. On the international front, if there is some degree of factor mobility (either commodities, capital or labor), the asymmetry of demographic change across countries and regions is particularly important for international capital flows and current account balances (Attanasio et al. 2016; Liu and

McKibbin 2019). The fundamental rationale is that demographic change affects aggregate saving and investment through changing the relative size of age cohorts who differ in saving rates and labor productivity, and hence affects domestic interest rates, which can drive cross-border capital flows due to arbitrage forces in the world capital markets. The real interest rate parity suggests that the real interest rate, adjusted by country risk premiums and expected changes in the real exchange rate, tends to be equal across countries unless there are capital controls.

This unprecedented global demographic change has been accompanied by another worldwide economic phenomenon that global current account imbalances (or global imbalances) have increased persistently around the world since the 1980s (Figure 4). One prominent pattern of the global imbalances is that capital has flowed from emerging economies to advanced countries, which is referred to as the uphill pattern. Particularly, North America has run persistent current account deficits while Asia especially China has run large surpluses. Capital outflows have also arised from Russia and other oil exporters. In addition, Japan and Germany, two of the most aging countries, have also run persistent surpluses. The persistent imbalances have raised concerns about long-term financial stability and resilience (IMF 2019a), and also been a political driver of the recent trade disputes between the United States and other countries especially China. The imbalances have stimulated extensive academic and policy debate (Gourinchas and Rey 2014). Especially after the global financial crisis, there has been an increasing debate on the relationship between the crisis and global imbalances (Obstfeld and Rogoff 2009; European Central Bank 2010; Chinn 2011). Whether the consequences of global imbalances are positive or negative depends on the causes. Both surpluses and deficits in current account balances can be good if the imbalances arise from desirable intertemporal choices but can be problems if domestic distortions cause the imbalances (Blanchard and Milesi-Ferretti 2011). The G20 and the IMF emphasize the need for further research on the drivers of global imbalances (IMF 2019a). There is an emerging literature that links the global demographic change to the global imbalances and estimates the contributions of asymmetric demographic change across countries to international capital flows.

Figure 4: Current account balances

(a) Current account (Trillion USD) (b) Current account (% GDP)




This paper explores the impacts of global demographic change on international capital flows with two contributions. First, we introudce demographic structure and pension systems into an otherwise standard overlapping-generation (OLG) model of a small open economy (e.g., Obstfeld and Rogoff 1996), and derive an analytical solution to the current account which depends on demographic and pension structure as well as other economic parameters. While the model is broadly related to all modeling studies of the demographic effects on international capital flows in the literature section later on, it is closely related to several theoretical studies that introduce demographic structure and pension systems into small OLG models of multiple countries (Krueger and Ludwig 2007; Adema et al. 2008; Ito and Tabata 2010; Eugeni 2015; Barany et al. 2018; Gannon et al. 2020). But there are two main differences. One is that, while multiple country models fail to produce analytical solutions, our model considers a small open economy and thus ensures an analytical solution which links a large number of factors to the current account transparently. For demographic structure, our solution includes the past, current and future fertility rates, and also the past, current and future mortality rates. The other is that our framework enables tractable analysis of both transition dynamics and steady states of any demographic shocks especially temporary shocks, while the above studies mostly focus on steady states with permanent demographic shocks.

Second, starting from our theoretical model, we provide an extensive review of the demographic studies on international capital flows. While many factors can drive capital flows across countries especially in the short term, this paper focuses on demographic change which contributes to medium- and long-term low-frequency capital movements. The literature falls into two broad strands from a time perspective. One strand projects the macroeconomic and cross-border impacts of future demographic change and pension reforms. This strand of studies often simulates projected demographic change and hypothetical pension reforms in general equilibrium models of open economies, and therefore illustrates how future demographic change shapes the landscape of the world economy, and also provides guidance for future pension policies. This literature is closely related to a large group of studies on future demographic change in general equilibrium models of closed economies, but introduces an additional channel of international capital flows. This channel provides potential opportunities for aging economies to invest retirement savings overseas and also for young economies to finance productive investment. The other strand focuses on historical current account imbalances and includes demographics as an explanatory factor or focuses on demographics alone. This strand of studies quantifies the contributions of historical demographic change to the past global imbalances either in general equilibrium models or in econometric models. Broadly speaking, demographics-driven international capital flows in the absence of institutional and financial frictions are desirable because young economies tend to borrow to finance investment while aging economies tend to save for retirement. Disentangling desirable and distorted components of current account imbalances is important for policy prognosis. For example, IMF (2019b) has been assessing external imbalance risks for about 50 countries since 2012 by estimating desirable imbalances that are consistent with economic fundamentals.

The remainder of this paper is organized as follows. Section 2 provides a two-period OLG model of a small open economy, and dervies an analytical solution which links a large set of factors including demographic and pension structure to the current account. Section 3 presents some theoretical results of various demographic shocks and some insights on the interaction between demographic shocks and productivity growth and pension structure. Section 4 reviews the modeling studies based on general equilibrium models of open economies, and covers a large number of issues including modeling strategy, shock nature, pension systems, youth dependency, geographic coverage, factor mobility, financial frictions, structural change, etc. Section 5 reviews empirical studies based on econometric models, and also covers a set of issues including construction of demographic variables, selection of non-demographic variables, estimation methods, etc. Section 6 concludes.

# 2 The model

## 2.1 The environment

Consider a small open economy. Time is discrete and infinite, $t = 0, 1, 2, ...$ There is an integrated international bonds market without frictions such that agents can freely borrow from and lend to the rest of the world. There is also a perfect domestic capital market such that domestic firms can freely rent capital for production. There is a homogeneous aggregate good in the world which can be traded without frictions in a perfect goods market. There is also a perfect domestic labor market, but labor is not mobile across countries. The government runs a balanced pay-as-you-go pension system financed by labor income taxes. All agents have perfect foresight except that households face mortality risks when they are old. The world interest rate is constant at $r$. All of the assumptions will be discussed in the review section.

## 2.2 Demographics

At the beginning of each period $t$, a new generation of homogeneous individuals with size $N_t^Y$ is born without assets. The size of each generation grows at a gross rate of $n_t$ as

$$N_t^Y = n_t N_{t-1}^Y \tag{1}$$

Thereafter, $n_t$ is interpreted as the fertility rate. If $n_t = 1$, population size remains stable given the mortality rate, and this fertility level is referred to as the replacement rate. Each individual lives up to two periods: young and old. They work when they are young, and retire when old. A young individual in period $t$ survives into retirement with a probability of $p_{t+1}$ at the beginning of period $t+1$. It follows that $1 - p_{t+1}$ represents the mortality rate in period $t+1$. Therefore, the size of each old generation is

$$N_{t+1}^O = p_{t+1} N_t^Y \tag{2}$$

Assume the survival probability increases over time as

$$p_{t+1} = p_t + \delta_{t+1} \tag{3}$$

where $\delta_t \geq 0$. This indicates that the mortality rate decreases by $\delta_t$ in period $t$.

## 2.3 Pension system

Assume there is a pension system. An old individual in period $t$ receives pension benefits $\rho_t w_{t-1}$, where $\rho_t$ is the replacement rate. The system is financed by taxing labor income of workers at rate $\tau_t$. Assume the system runs a balanced budget each period.

$$N_t^Y \tau_t w_t = N_t^O \rho_t w_{t-1} \tag{4}$$

Equivalently,

$$\rho_t = n_t \tau_t \frac{w_t}{p_t w_{t-1}} \tag{5}$$

If $\rho_t = 0$, the system becomes completely pre-funded, where all retirees finance their consumption by private saving when they are young.

## 2.4 Consumers

Each individual inelastically supplies one unit of labor in a competitive labor market when she is young, and retires when she is old. Wage is denoted by $w_t$. An individual born in period $t$ makes a decision on consumption $c_t^Y$ and saving $s_t^Y$ at the end of period $t$, where the saving partly goes to foreign assets $b_{t+1}^O$, and partly goes to domestic capital $k_{t+1}^O$. The rate of return on capital is denoted by $\tilde{r}_t$. Assume there is a perfect annuity market through which each agent writes a contract with the members of her generation that makes the survivors share the assets or debts of those who die prematurely. This arrangement insures away the risk of unintended bequests, so the assets or debts held by the individuals who die before retirement are transferred to those who survive into retirement. The period budget constraints of an individual born in period $t$ are

$$c_t^Y + b_{t+1}^O + k_{t+1}^O = (1-\tau_t)w_t \tag{6}$$

$$c_{t+1}^O = \frac{(1+r)b_{t+1}^O + (1+\tilde{r}_{t+1})k_{t+1}^O}{p_{t+1}} + \rho_{t+1}w_t \tag{7}$$

where the first equation is for the young period and the second one is for the old period. A perfect international asset market implies no arbitrage opportunities in equilibrium.

$$\tilde{r}_t = r \tag{8}$$

This implies the intertemporal budget constraint as

$$c_t^Y + p_{t+1}\frac{c_{t+1}^O}{1+r} = \omega_t \tag{9}$$

where $\omega_t$ denotes lifetime wealth of an individual born in period $t$ defined as

$$\omega_t = (1-\tau_t)w_t + p_{t+1}\frac{\rho_{t+1}w_t}{1+r} \tag{10}$$

Each individual born at time $t$ makes a consumption plan $\{c_t^Y, c_{t+1}^O\}$, subject to the intertemporal budget constraint, to maximize her lifetime utility

$$E_t\{u(c_t^Y, c_{t+1}^O)\} = \frac{(c_t^Y)^{1-1/\sigma}}{1-1/\sigma} + \beta p_{t+1}\frac{(c_{t+1}^O)^{1-1/\sigma}}{1-1/\sigma} \tag{11}$$

where $\sigma > 0$ denotes the elasticity of intertemporal substitution, and $0 < \beta < 1$ denotes the subjective discount factor. The optimal consumption for each individual can be solved as

$$c_t^Y = \frac{\omega_t}{1+p_{t+1}(1+r)^{\sigma-1}\beta^\sigma}, \quad c_{t+1}^O = \frac{(1+r)^\sigma\beta^\sigma\omega_t}{1+p_{t+1}(1+r)^{\sigma-1}\beta^\sigma} \tag{12}$$

The young individual's saving is

$$s_t^Y = (1-\tau_t)w_t - c_t^Y = (1-\tau_t)w_t - \frac{(1-\tau_t)w_t + p_{t+1}\frac{\rho_{t+1}w_t}{1+r}}{1+p_{t+1}(1+r)^{\sigma-1}\beta^\sigma} \tag{13}$$

The old individual's saving is

$$s_{t+1}^O = \frac{1}{p_{t+1}}rs_t^Y + \rho_{t+1}w_t - c_{t+1}^O = -\frac{1}{p_{t+1}}s_t^Y \tag{14}$$

## 2.5 Firms

There is an aggregate production sector. A representative firm hires capital and labor to produce output in a Cobb-Douglas production function as

$$Y_t = A_t(K_t)^{\alpha}(L_t)^{1-\alpha} \tag{15}$$

where $Y_t, K_t, L_t, A_t$ denote output, capital, labor and total factor productivity (TFP) in period $t$, respectively. Suppose that TFP rises over time as follows.

$$A_{t+1} = g_{t+1}^{1-\alpha} A_t \tag{16}$$

where the gross rate of TFP growth is $g_{t+1}^{1-\alpha}$, which is equivalent to a gross rate $g_{t+1}$ of labor productivity growth given the Cobb-Douglas production function. Capital accumulates through investment $I_t$ without depreciation.

$$K_{t+1} = K_t + I_t \tag{17}$$

The firm maximizes the present value of entire profits as

$$\Pi = \sum_{t=0}^{\infty} \left( \prod_{s=0}^{t} \frac{1}{1+\tilde{r}_s} \right) (Y_t - w_t L_t - I_t) \tag{18}$$

Denote the capital-labor ratio by $k_t = K_t/L_t$. The first-order conditions for the firm are

$$\tilde{r}_t = \alpha A_t (k_t)^{\alpha-1} \tag{19}$$

$$w_t = (1-\alpha) A_t (k_t)^{\alpha} \tag{20}$$

## 2.6 Equilibrium

**Definition 1.** Given the world interest rate and the initial state of the economy, a recursive equilibrium is a set of policy functions $\{c_t^Y, c_t^O, b_{t+1}^O, k_{t+1}^O\}_{t=0}^{\infty}$ for households, and wages $\{w_t\}_{t=0}^{\infty}$ such that

(a) Aggregate and individual behaviors are consistent: aggregate consumption $C_t$, aggregate saving $S_t$, aggregate foreign assets $B_{t+1}$, and aggregate capital stock $K_{t+1}$ are the sums of their respective individual counterparts over all alive individuals.

$$C_t = N_t^Y c_t^Y + N_t^O c_t^O \tag{21}$$

$$S_t = N_t^Y s_t^Y + N_t^O s_t^O \tag{22}$$

$$K_{t+1} = N_t^Y k_{t+1}^O \tag{23}$$

$$B_{t+1} = N_t^Y b_{t+1}^O \tag{24}$$

(b) Capital accumulates through investment:

$$K_{t+1} = K_t + I_t \tag{25}$$

(c) The labor market clears:

$$L_t = N_t^Y \tag{26}$$

(d) The goods market clears:

$$Y_t = C_t + I_t + T_t \tag{27}$$

where $T_t$ represents trade balance in period $t$.

(e) The domestic capital market clears:

$$S_t = K_{t+1} - K_t + B_{t+1} - B_t = I_t + CA_t \tag{28}$$

where $CA_t$ represents the current account in period $t$.

(f) The international asset market clears:

$$\tilde{r}_t = r \tag{29}$$

Combining the equilibrium conditions yields the solutions to the capital-labor ratio and the wage rate, which are determined by the world interest rate and the TFP level.

$$k_t = \left(\frac{\alpha A_t}{r}\right)^{\frac{1}{1-\alpha}} \tag{30}$$

$$w_t = A_t\left(\frac{\alpha A_t}{r}\right)^{\frac{\alpha}{1-\alpha}} \tag{31}$$

## 2.7 National saving, investment and current account

Given the above equilibrium, we can derive national saving, investment and hence the current account in terms of output. The saving of each young generation in terms of output is

$$\frac{S_t^Y}{Y_t} = \frac{N_t^Y s_t^Y}{Y_t} = \frac{s_t^Y}{y_t} = (1-\alpha)\frac{(1-\tau_t)p_{t+1}(1+r)^\sigma\beta^\sigma - p_{t+1}\rho_{t+1}}{1+r+p_{t+1}(1+r)^\sigma\beta^\sigma} \tag{32}$$

where $y_t$ represents output per worker. Given the pension replacement rate, the pension tax rate is

$$\tau_t = \frac{p_t\rho_t}{n_t}\frac{w_{t-1}}{w_t} = \frac{p_t\rho_t}{n_t g_t} \tag{33}$$

Combining the above two equations yields

$$\frac{S_t^Y}{Y_t} = (1-\alpha)\frac{\left(1-\frac{p_t\rho_t}{n_t g_t}\right)p_{t+1}(1+r)^\sigma\beta^\sigma - p_{t+1}\rho_{t+1}}{1+r+p_{t+1}(1+r)^\sigma\beta^\sigma} \tag{34}$$

The saving of each old generation in terms of output is

$$\frac{S_{t+1}^O}{Y_{t+1}} = \frac{N_{t+1}^O s_{t+1}^O}{Y_{t+1}} = \frac{p_{t+1}N_t^Y s_{t+1}^O}{Y_t}\frac{Y_t}{Y_{t+1}} = -\frac{1}{n_{t+1}g_{t+1}}\frac{S_t^Y}{Y_t} \tag{35}$$

The negative sign indicates that the old generation decummulates their assets. The term $1/(n_{t+1}g_{t+1})$ reflects a scale effect of output change because the saving of the old generation, $S_{t+1}^O$, depends on the output in period $t$ while $Y_{t+1}$ represents the output in period $t+1$. The aggregate saving in terms of output is therefore

$$\frac{S_t}{Y_t} = \frac{S_t^Y + S_t^O}{Y_t} = \frac{S_t^Y}{Y_t} - \frac{1}{n_t g_t}\frac{S_{t-1}^Y}{Y_{t-1}} \tag{36}$$

The aggregate investment in terms of output is

$$\frac{I_t}{Y_t} = \frac{K_{t+1} - K_t}{Y_t} = \frac{K_{t+1}}{Y_{t+1}}\frac{Y_{t+1}}{Y_t} - \frac{K_t}{Y_t} = \frac{(n_{t+1}g_{t+1}-1)\alpha}{r} \tag{37}$$

The current account in terms of output is

$$
\begin{aligned}
\frac{CA_t}{Y_t} = \frac{S_t - I_t}{Y_t} =&(1-\alpha)\frac{p_{t+1}(1+r)^{\sigma}\beta^{\sigma}\left(1-\frac{p_t\rho_t}{n_tg_t}\right)-p_{t+1}\rho_{t+1}}{1+r+p_{t+1}(1+r)^{\sigma}\beta^{\sigma}} \\
&-(1-\alpha)\frac{1}{n_tg_t}\frac{p_t(1+r)^{\sigma}\beta^{\sigma}\left(1-\frac{p_{t-1}\rho_{t-1}}{n_{t-1}g_{t-1}}\right)-p_t\rho_t}{1+r+p_t(1+r)^{\sigma}\beta^{\sigma}} \\
&-\frac{(n_{t+1}g_{t+1}-1)\alpha}{r}
\end{aligned} \tag{38}
$$

The current account consists of three components: the first part represents the saving of the young generation, and the second part represents the saving of the old generation, while the last part represents investment. The above equation indicates that the current account depends on: (1) the past, current and future fertility rates, (2) the past, current and future mortality rates, (3) the past, current and future pension replacement rates, (4) the past, current and future productivity growth rates, (5) the real interest rate, (6) the elasticity of intertemporal substitution in consumption, (7) the elasticity of output with respect to capital and labor, and (8) the subjective discount factor.

For simplicity, we assume $(1+r)\beta = 1$ such that consumers would choose a flat consumption path without a tilting motive when the mortality rate is zero. This assumption eliminates the effect of the elasticity of intertemporal substitution. Therefore, the above equation reduces to

$$
\begin{aligned}
\frac{CA_t}{Y_t} =&(1-\alpha)\left\{\frac{p_{t+1}\left(1-\frac{p_t\rho_t}{n_tg_t}\right)-p_{t+1}\rho_{t+1}}{1+r+p_{t+1}} - \frac{1}{n_tg_t}\frac{p_t\left(1-\frac{p_{t-1}\rho_{t-1}}{n_{t-1}g_{t-1}}\right)-p_t\rho_t}{1+r+p_t}\right\} \\
&-\frac{(n_{t+1}g_{t+1}-1)\alpha}{r}
\end{aligned} \tag{39}
$$

Demographic change drives international capital flows through changing the real interest rate in this model. Imposing a zero balance on the current account in (38), we can obtain the interest rate in autarky. Consider a steady state where the parameters are constant without time subscripts. The autarky interest rate in the steady state is determined by

$$
p(1-\alpha)\frac{(1+\tilde{r})^{\sigma}\beta^{\sigma}\left(1-\frac{p\rho}{ng}\right)-\rho}{1+\tilde{r}+p(1+\tilde{r})^{\sigma}\beta^{\sigma}} = \frac{(ng-1)\alpha}{\tilde{r}} \tag{40}
$$

This is a special case of the autarky interest rate condition in Barany et al. (2018) who introduce demographic structure and pension systems into a three-period OLG model (child, worker and retiree). Given empirically plausible parameter values, the above condition implies the following proposition which is drawn from Barany et al. (2018).

**Proposition 1** *In a closed economy with perfect markets for goods and factors, the autarky interest rate in the steady state is determined by* (40)*. The autarky interest rate*

*(a) increases in the fertility rate;*

*(b) increases in the mortality rate;*

*(c) increases in the replacement rate.*

This proposition is useful for understanding the demographic effects on international capital flows, and also establishes a link between the literature about the demographic effects on international capital flows and the literature about the demographic effects on real interest rates in closed economies (as discussed later on).

# 3 Demographic effects

Based on the above model, we now investigate the effects of several demographics-related factors on international capital flows. The first one is demographic change alone, and the second one is the interaction between demographic change and productivity growth, and the third one is the interaction between demographic change and pension structure. The last part examines the role of the world interest rate as a way of illustrating the effect of foreign demographic change. Without loss of generality, we assume that the net foreign asset poisition and the current account are initially in balance before demographic shocks occur.

## 3.1 Demographic change

We first assume that TFP is constant across generations, $g_t = 1$, and there is no pension system, and consider the effect of demographic change alone. The current account in terms of output reduces to

$$\frac{CA_t}{Y_t} = (1-\alpha)\left\{1 - \frac{1}{1+p_{t+1}(1+r)^{-1}} - \frac{1}{n_t}\left(1 - \frac{1}{1+p_t(1+r)^{-1}}\right)\right\} - \frac{(n_{t+1}-1)\alpha}{r} \quad (41)$$

The current account in terms of output increases in the current fertility rate because of the scale effect of output change, and decreases in the future fertility rate because of the effect on investment. The current account in terms of output increases in the current mortality rate because the old generation dis-save less given they save less when young if they face high mortality, and decreases in the future mortality rate because the young generation saves less if they face high mortality. We consider both fertility and mortality shocks which can be either transitory or permanent. Suppose that the fertility rate remains at one and the mortality rate remains at $\bar{p}$ $(0 < \bar{p} < 1)$ until period $s$, and demographic shocks occur in period $s+1$. It follows that $CA_t = 0$ for $t \leq s-1$.

### (1) Fertility change

Suppose that the mortality rate remains constant at $\bar{p}$ forever. We consider three scenarios of fertility shocks. Generally speaking, fertility change affects national saving and also investment, but the effect on investment dominates the effect on saving.

### (a) Temporary fertility shock with permanent change in population size

Suppose that the fertility rate increases in period $s+1$, and then returns to one afterwards. Therefore, total population increases in period $s+1$, and then flattens forever. (41) suggests that the current account is in deficit in period $s$, and in surplus in period $s+1$, and returns to balance afterwards. Intuitively, capital flows in at the end of period $s$ to finance investment for the additional young individuals born in period $s+1$. At the end of period $s+1$, the additional young individuals save part of their labor income for retirement while investment returns to zero, so part of the foreign capital would flow out. The current account returns to balance afterwards. Therefore, the economy accumulates external debt in period $s$, which partly reduces in period $s+1$ and remains constant afterwards.

### (b) Temporary fertility shock with temporary change in population size

Suppose that the fertility rate increases in period $s+1$, and then decreases below one such that the size of the young generation remains at the pre-shock level, and then returns to one afterwards. Total population increases in periods $s+1$ and $s+2$, and then decreases to the pre-shock level afterwards. Capital flows in at the end of period $s$ to finance investment for the additional young individuals born in period $s+1$. At the end of period $s+1$, national saving increases while investment decreases to be negative given labor force decreases in period $s+2$, so foreign capital completely flows out, leaving zero foreign assets, with the current account in balance afterwards.

**(c) Permanent fertility shock with persistent change in population size**

Suppose that the fertility rate deviates from one and remains at a constant level at $n$ from period $s+1$ onwards. Total population either expands ($n > 1$) or shrinks ($n < 1$) persistently. The economy experiences a transition from period $s$ to $s+1$, and reaches a new steady state afterwards. Take $n > 1$ as an example. During the transition, national saving remains unchanged but investment increases, so capital flows in at the end of period $s$. In the steay state after period $s$, capital continues to flow in but at a smaller scale because the additional young individuals save part of their labor income each period. Mathematically, the current account in terms of output is

$$\frac{CA}{Y} = (n-1)\left\{\frac{1-\alpha}{n}\left(1-\frac{1}{1+\bar{p}(1+r)^{-1}}\right)-\frac{\alpha}{r}\right\} \tag{42}$$

It is empirically plausible to assume the RHS is negative. If fertility increases, the current account is in deficit persistently, and capital flows in continuously, and the foreign asset position decreases continuously. If fertility decreases, capital flows out persistently, and the foreign asset position increases continuously.

**(2) Mortality change**

Suppose that the fertility rate remains at one forever. We consider two scenarios of mortality shocks. Mortality change only affects national saving but not investment.

**(a) Permanent mortality shock**

Suppose that the mortality rate decreases in period $s+1$ and then flattens forever. The young generation remains stable, the old generation increases permanently, and hence total population increases permanently. Capital flows out at the end of period $s$. The current account returns to balance afterwards, leaving constant foreign assets forever.

**(b) Persistent mortality shock**

Suppose that the mortality rate decreases from period $s+1$ onwards, and converges to zero over an infinite time. Equivalently, the survival rate converges to one and the longevity converges to a finite level of two periods. The young generation remains stable, the old generation increases persistently, and hence total population increases persistently. Assuming $n = 1$, the current account in terms of output reduces to

$$\frac{CA_t}{Y_t} = (1-\alpha)\left\{\frac{1}{1+p_t(1+r)^{-1}}-\frac{1}{1+p_{t+1}(1+r)^{-1}}\right\} \tag{43}$$

As $p_{t+1} > p_t$, the current account is in surplus persistently. Capital flows out every period, and the economy accummulates foreign assets continuously. Therefore, the current account in terms of output increases in longevity or decreases in mortality.

The above analysis of fertility and mortality changes has presented the pure effect of demographic change on international capital flows, as summarized below.

**Proposition 2** *In a small open economy with perfect markets for goods, factors and assets, and without cross-border labor mobility, in the absence of productivity growth and pension systems, assuming* $(1+r)\beta = 1$*, the current account in terms of output is*

$$\frac{CA_t}{Y_t} = (1-\alpha)\left\{1 - \frac{1}{1+p_{t+1}(1+r)^{-1}} - \frac{1}{n_t}\left(1 - \frac{1}{1+p_t(1+r)^{-1}}\right)\right\} - \frac{(n_{t+1}-1)\alpha}{r}.$$

*(a) The current account in terms of output increases in the current fertility rate while decreasing in the future fertility rate, and increases in the current mortality rate while decreasing in the future mortality rate;*

*(b) If the fertility rate increases for one period and then returns to the replacement level, capital flows in for the first period, and partly flows out for the next period, leaving constant foreign debt afterwards;*

*(c) If the fertility rate increases for one period and decreases for the next period and then returns to the replacement level such that population size remains stable, capital flows in for the first period, and completely flows out for the next period, leaving zero foreign assets afterwards;*

*(d) If the fertility rate increases permanently, capital flows in persistently and foreign debt increases continuously, and vice versa;*

*(e) If the mortality rate decreases permanently, capital flows out for the first period and the current account returns to balance afterwards, leaving constant foreign assets;*

*(f) If the mortality rate decreases persistently, capital flows out persistently and foreign assets increase continuously.*

## 3.2 Productivity growth

Suppose that TFP rises over time, i.e., $g_t > 1$. The current account in terms of output reduces to

$$\frac{CA_t}{Y_t} = (1-\alpha)\left\{1 - \frac{1}{1+p_{t+1}(1+r)^{-1}} - \frac{1}{n_t g_t}\left(1 - \frac{1}{1+p_t(1+r)^{-1}}\right)\right\} - \frac{(n_{t+1}g_{t+1}-1)\alpha}{r} \tag{44}$$

The current account in terms of output increases in the current productivity growth because of the scale effect of output change, and decreases in the future productivity growth because of the effect on investment. This indicates that productivity growth can affect both national saving and investment. In addition, given $n_t g_t = 1 + (n_t - 1) + (g_t - 1) + (n_t - 1)(g_t - 1)$, the current account in terms of output depends on labor growth and productivity growth separately and also interactively. This interactive channel is consistent with the variable-rate-of-growth model (Mason 1988). If $n_t = 1$ and $p_t = \bar{p}$, the current account in terms of output reduces to

$$\frac{CA_t}{Y_t} = (1-\alpha)\left(1 - \frac{1}{g_t}\right)\left(1 - \frac{1}{1+\bar{p}(1+r)^{-1}}\right) - \frac{(g_{t+1}-1)\alpha}{r} \tag{45}$$

This captures the effect of productivity growth when demographic structure is stable. If productivity growth remains at one until period $s$, and increases temporarily in period $s+1$ and then returns to one afterwards. Capital flows in at the end of period $s$, and partly flows out at the end of period $s+1$ because of the scale effect of output change. If productivity growth increases permanently in period $s+1$, capital flows in continuously. If fertility decreases but productivity increases, the overall effect on the current account depends on which effect dominates.

**Proposition 3** *In a small open economy with perfect markets for goods, factors and assets, and without cross-border labor mobility, in the absence of pension systems, assuming* $(1+r)\beta = 1$*, the current account in terms of output is*

$$\frac{CA_t}{Y_t} = (1-\alpha)\left\{1 - \frac{1}{1+p_{t+1}(1+r)^{-1}} - \frac{1}{n_t g_t}\left(1 - \frac{1}{1+p_t(1+r)^{-1}}\right)\right\} - \frac{(n_{t+1}g_{t+1}-1)\alpha}{r}.$$

*(a) The current account in terms of output increases in the current productivity growth and decreases in the future productivity growth;*

*(b) The current account in terms of output increases in the product of the current productivity growth and fertility growth, and decreases in the product of the future productivity growth and fertility growth;*

*(c) If productivity growth increases temporarily for one period, capital flows in for the first period, and partly flows out for the next period, leaving constant foreign debt afterwards;*

*(d) If productivity growth increases permanently, capital flows in continuously, and foreign debt increases continuously;*

*(e) If population shrinks persistently but productivity increases persistently such that the product of fertility and productivity growth remains at one, the current account remains in balance.*

## 3.3 Pension system

We now consider the effect of pension systems. It follows from (37) that investment in terms of output is unchanged compared to the case of no pension systems. This is because pension systems do not affect labor supply in our model where households supply labor inelastically and retire at a fixed age. But pension systems can affect national saving. It follows from (39) that the current account in terms of output increases in the past replacement rate, and can either increase or decrease in the current replacement rate, and decreases in the future replacement rate. In addition, the replacement rate interacts with the survival rate or the mortality rate. The fertility rate affects the current account through an additional channel of changing lifetime wealth in addition to the scale effect and the investment effect. This additional channel leads to more dynamics in the current account transition. We consider several scenarios below which are comparable with the scenarios without pension systems above.

### (1) Pension reform

Consider $n_t = 1, p_t = \bar{p}, g_t = 1$. The current account in terms of output reduces to

$$\frac{CA_t}{Y_t} = (1-\alpha)\bar{p}\frac{\bar{p}(\rho_{t-1}-\rho_t)+(\rho_t-\rho_{t+1})}{1+r+\bar{p}} \tag{46}$$

Suppose that the pension replacement rate remains at a positive level until period $s$, and decreases in period $s+1$ and flattens afterwards. Capital flows out in period $s+1$ because the old generation dis-saves less given they receive less pension benefits, and further flows out in period $s+2$ because the young generation saves more given they expect less pension benefits. The current account returns to balance afterwards, leaving constant foreign assets.

**(2) Temporary fertility shock**

Consider $g_t = 1, p_t = \bar{p}, \rho_t = \rho$. The current account in terms of output reduces to

$$\frac{CA_t}{Y_t} = (1-\alpha)\left\{\frac{\bar{p}\left(1-\frac{\bar{p}\rho}{n_t}\right)-\bar{p}\rho}{1+r+\bar{p}} - \frac{1}{n_t}\frac{\bar{p}\left(1-\frac{\bar{p}\rho}{n_{t-1}}\right)-\bar{p}\rho}{1+r+\bar{p}}\right\} - \frac{(n_{t+1}-1)\alpha}{r} \tag{47}$$

Suppose that the fertility rate increases in period $s+1$ and then returns to one afterwards. The current account is in deficit in period $s$ because capital flows in to finance investment for the additional young individuals born in period $s+1$, and is in surplus in period $s+1$ because the young generation saves more due to the larger size and the old generation dis-save less due to the scale effect, and is in defit in period $s+2$ because the old generation dis-saves more due to the larger size. The current account returns to balance afterwards.

**(3) Permanent fertility shock**

Consider $g_t = 1, p_t = \bar{p}, \rho_t = \rho$. The current account in terms of output reduces to

$$\frac{CA_t}{Y_t} = (1-\alpha)\left\{\frac{\bar{p}\left(1-\frac{\bar{p}\rho}{n_t}\right)-\bar{p}\rho}{1+r+\bar{p}} - \frac{1}{n_t}\frac{\bar{p}\left(1-\frac{\bar{p}\rho}{n_{t-1}}\right)-\bar{p}\rho}{1+r+\bar{p}}\right\} - \frac{(n_{t+1}-1)\alpha}{r} \tag{48}$$

Suppose that the fertility rate increases in period $s+1$ permanently, and thus total population expands persistently. The economy experiences a transition from period $s$ to $s+2$, and reaches a new steady state afterwards. The transition takes one more period than the case of no pension systems because of the interaction between fertility change and pension systems. In the steady state, capital flows in continuously, and foreign debt increases persistently.

**(4) Permanent mortality shock**

Consider $n_t = 1, g_t = 1, \rho_t = \rho$. The current account in terms of output reduces to

$$\frac{CA_t}{Y_t} = (1-\alpha)\left\{\frac{p_{t+1}\left(1-p_t\rho-\rho\right)}{1+r+p_{t+1}} - \frac{p_t\left(1-p_{t-1}\rho-\rho\right)}{1+r+p_t}\right\} \tag{49}$$

Suppose that $p_{s+1}$ increases and flattens forever. The current account is in surplus in period $s$ because the young generation save more for retirement, and is also in surplus in period $s+1$ because the young generation saves less and the old generation dis-saves more, and is in deficit in period $s+2$ because the old generation dis-saves less given they save less when young. The current account is in balance afterwards, leaving constant foreign assets.

**Proposition 4** *In a small open economy with perfect markets for goods, factors and assets, and without cross-border labor mobility, assuming* $(1+r)\beta = 1$*, the current account in terms of output is*

$$\frac{CA_t}{Y_t} = (1-\alpha)\left\{\frac{p_{t+1}\left(1-\frac{p_t\rho_t}{n_tg_t}\right)-p_{t+1}\rho_{t+1}}{1+r+p_{t+1}} - \frac{1}{n_tg_t}\frac{p_t\left(1-\frac{p_{t-1}\rho_{t-1}}{n_{t-1}g_{t-1}}\right)-p_t\rho_t}{1+r+p_t}\right\} - \frac{(n_{t+1}g_{t+1}-1)\alpha}{r}.$$

*(a) The current account in terms of output increases in the past replacement rate, and either increases or decreases in the current replacement rate, and decreases in the future replacement rate;*

*(b) The replacement rate affects the current account in terms of output through its interaction with the mortality rate;*

*(c) If the replacement rate decreases permanently, capital flows out for the first period, and further flows out for the second period, leaving constant foreign assets afterwards;*

*(d) If the fertility rate increases for one period and then returns to one, capital flows in for the first period, and partly flows out for the second period, and then flows in for the third period, leaving constant foreign debt afterwards;*

*(e) If the fertility rate increases permanently, capital flows in persistently, accumulating foreign assets persistently;*

*(f) If the mortality rate decreases permanently, capital flows out for the first period, and further flows out for the second period, and partly flows in for the third period, leaving constant foreign assets afterwards.*

## 3.4 Foreign demographic change

The model considers a small open economy assuming no demographic shocks in the foreign world, and thus cannot examine the impacts of relative demographic change directly. To consider relative demographic change in a small open economy model, we suppose that foreign demographic shocks change the world interest rate, and thus affect the effects of domestic demographic shocks on the current account.

To illustrate the role of the interest rate change, we abstract from pension systems, and assume mortality is constant at $\bar{p}$, and fertility and productivity are also constant, so we can compare two steady states with different interest rates. (38) reduces to

$$\frac{CA}{Y} =(ng-1)\left\{\frac{1-\alpha}{ng}\left(1-\frac{1}{1+\bar{p}(1+r)^{\sigma-1}\beta^{\sigma}}\right)-\frac{\alpha}{r}\right\} \tag{50}$$

The interest rate change affects the current account in terms of output through changing both saving and investment. On the consumption side, the interest rate change has two effects on consumption and saving: substitution and income effects. The net outcome of the two effects is governed by the elasticity of intertemporal substitution. If $\sigma = 1$, the two effects completely offset each other. If $\sigma > 1$, when the interest rate increases, the young generation tends to tilt up their consumption path and thus increase saving. If $\sigma < 1$, when the interest rate increases, the young generation tends to tilt down their consumption path and thus decrease saving. On the production side, investment (or disinvestment) in terms of output decreases in the interest rate because it is determined by capital intensity. The higher the interest rate, the lower capital stock and hence the lower capital intensity. Mathmetically,

$$\frac{\partial(CA/Y)}{\partial r} = (ng-1)\left\{\frac{1-\alpha}{ng}\frac{\bar{p}(\sigma-1)(1+r)^{\sigma-2}\beta^{\sigma}}{(1+\bar{p}(1+r)^{\sigma-1}\beta^{\sigma})^2}+\frac{\alpha}{r^2}\right\} \tag{51}$$

It is empirically plausible to assume that the part in the curly bracket is positive, which implies that the effect on investment dominates the effect on saving. Therefore, if $ng > 1$, the current account in terms of output decreases in the interest rate, and vice versa. The two cases together suggest that the demographic effect on international capital flows in terms of output decreases in the world interest rate, as summarized below.

**Proposition 5** *In a small open economy with perfect markets for goods, factors and assets, and without cross-border labor mobility, the effect of demographic shocks on international capital flows in terms of output decreases in the world interest rate.*

To conclude this section, Table 1 summarizes the effects of demographic shocks on the current account balance and the net foreign assets in terms of output. The first column indicates the driver of demographic change, and the second column indicates whether the shock is temporary, permanent or persistent, and the third column indicates whether the change of population size is temporary, permanent, or persistent. The fourth and fifth columns indicate that productivity growth interacts with fertiltiy change, while pension generosity interacts with mortality change. The last two columns indicate that the effects of demographic change on the current account balance can be either temporary or permanent, and the effects on the net foreign asset poisition can be either temporary, permanent, or persistent, depending on the demographic drivers and the shock persistence.

Table 1: Demographic effects on current accounts and foreign assets

| **Demographic driver** | **Shock persistence** | **Population size** | **Productivity growth** | **Pension system** | **Current account** | **Foreign asset** |
|---|---|---|---|---|---|---|
| Fertility | Temporary | Permanent | Interactive | No | Temporary | Permanent |
| | Temporary | Temporary | Interactive | No | Temporary | Temporary |
| | Permanent | Persistent | Interactive | No | Permanent | Persistent |
| Mortality | Permanent | Permanent | No | Interactive | Temporary | Permanent |
| | Persistent | Persistent | No | Interactive | Permanent | Persistent |

# 4 Modeling studies

There is an emerging literature that investigates the international aspects of demographic change in general equilibrium models of open economies. From a time perspective, the literature falls into two broad strands. One strand focuses on historical global imbalances, and includes demographics as one of the contributors or focuses on demographics alone. The other focuses on future demographic change, and projects the macroeconomic impacts into the future, including fiscal impacts and external balances. Almost all studies focus on time periods after 1970 when the Bretton Woods system broke down. This section organizes the literature into a number of groups from a modeling perspective, starting with the studies of modeling basic demographic elements followed by the studies of introducing more complex demographic issues. For each group of the studies, if one focuses on the past global imbalances, we will highlight how well the modeling results capture historical capital flows, indicating which modeling elements might be important.

While this section focuses on open-economy studies, it is worth noting that the studies that examine the demographic impacts on real interest rates in closed economies are also relevant for this paper because capital flows across borders through the interest rate channel. This group of studies find strong evidence that population aging can significantly reduce the real interest rate especially in advanced economies. For example, Miles (1999) shows that population aging would decrease the real interest rate over the period of 2000-2030 by 30 basis points in the United Kingdom and by over 40 basis points in Europe. Borsch-Supan et al. (2001) show that population aging would decrease the real interest rate over the period of 2010-2025 by about 50 basis points in Germany. Some studies show that demographic change can explain a significant fraction of the declines in the real interest rate in the last several decades in the United States (Carvalho et al. 2016;

Gagnon et al. 2016; Lisack et al. 2017; Jones 2018), and in Japan (Fujita and Fujiwara 2016; Sudo and Takizuka 2018), and in Euro area (Papetti 2021a).

## 4.1 Modeling approaches

There are several broad approaches to introducing demographic structure into general equilibrium models, as summarized below. Appendix A provides more technical details for the approaches.

#### (1) The overlapping generation approach

The OLG approach is the most common one, where agents of each generation live for a finite time period and overlap with one or more periods of other generations. This approach departs from the standard infinite-horizon representative agent models by differentiating generations by age. Samuelson (1958) builds a two-period OLG model of an endowment economy while Diamond (1965) builds a two-period OLG model of a production economy. Auerbach and Kotlikoff (1987) extend OLG models from two periods to multiple periods and propose a computational algorithm of solving large-scaled OLG models. Most simulation-based OLG models follow Auerbach and Kotlikoff (1987)'s computational approach. Attanasio et al. (2016) provide a review of the development of OLG models. As a seminal contribution, Buiter (1981) builds a two-country OLG model to analyze international capital flows.

#### (2) The perpetual youth approach

The perpetual youth approach assumes that agents face a probability of death each period. This approach differentiates cohorts by life stage rather than by natural age. There are a number of variants of the perpetual youth approach. Yaari (1965) introduces uncertain lifetime by assuming the time horizon is a random variable. Blanchard (1985) assumes that agents face a constant death rate each period, and a new cohort is born with the birth rate equal to the death rate such that population size is stationary. Weil (1989) assumes no probability of death but a positive birth rate, i.e., individuals live forever and a new cohort is born each period. Buiter (1988) separates birth and death rates more generally. The assumption of a constant death rate independent of age introduces finite horizon, and allows analytical solutions even with different cohorts. However, as consumption and saving propensities are independent of age, changes in age structure hardly affect aggregate consumption and saving. To mitigate this issue, Gertler (1999) introduces two life stages: work and retirement, with a constant transition probability per period for a worker into retirement and also a constant probability per period for a retiree to death. This model allows different propensities of consumption and saving at the two stages. Batsuuri (2021) extends the model from two to four stages (children, young worker, old worker, and retiree), with a transition probability per period from one stage to the next stage. Grafenhofer et al. (2006) extend the model from two to multiple stages more generally. There is a trade-off that more stages allow richer life cycle patterns but lead to less tractability, and also bring the approch closer to the OLG approach. Grafenhofer et al. (2006) show that eight stages can produce a close approximation of empirical life-cycle patterns. Instead of increasing life stages, Faruqee et al. (1997) introduce an age-productivity profile into Blanchard (1985)'s approach, and distribute aggregate labor income to individuals according to age-specific weights. This top-down approach implies that changes in the age distribution have no aggregate implications. To allow aggregate implications, Faruqee (2002) aggregates individual labor productivity from bottom up and then determines wage through aggregate labor supply and demand.

### (3) The dependency approach

This approach establishes a macroeconomic link between dependency ratios and saving rates (or consumption rates) based on regression analysis, and then incorporates such a link into general equilibrium models where infinite horizon is introduced in the perpetual youth approach (e.g., Masson and Tryon 1990). This approach presents no life cycle features, and has two drawbacks. One is that the approach focuses on the effect of demographic structure on consumption, but misses the effect on production, so the estimation of demographic structure on saving rates is biased because it picks up the effect on investment. The other is that the macroeconomic model misses the effect on investment. This also concerns the distinction between partial-equilibrium and general-equilibrium analysis (Bryant and McKibbin 1998).

### (4) The population-weighted Ramsay approach

This approach follows the Ramsey growth model but considers a social welfare function where individual utility is summed over population (e.g., Cutler et al. 1990; Floden 2003). Population size is then linked to labor size and the support ratio (the ratio of working-age population to total population). This approach has no life-cycle features either. Demographic transitions change labor size and the support ratio.

## 4.2 Nature of demographic shocks

The modeling studies investigate a variety of demographic shocks over different time periods for different countries and/or regions. This part highlights the nature of demographic shocks along four dimensions.

### (1) Demographic drivers

A demographic shock can be driven by either fertility change or mortality change or both. The global demographic change since WWII is a combination of fertility and mortality changes. The macroeconomic consequences and international implications heavily depend on the combination of the causes (Faruqee 2002; Bryant 2004a; Fehr et al. 2008).

### (2) Shock persistence

Demographic shocks can be either transitory or permanent or a combination (e.g., a transitory fertility shock and a permanent mortality shock). The baby boom after WWII and subsequent fertility bust was a transitory shock. But if one focuses on the period after the baby boom, the gradual decrease in fertility, if assumed to converge to the replacement rate in the long run, is a permanent shock. However, if the fertility rate decreases well below the replacement rate but is projected to return to the replacement rate eventually, the transition becomes a transitory shock again. For example, Japan's fertility rate was around the replacement rate in 1970 (2.12 children per woman) and fell gradually to 1.36 in 2020, but is projected to return to the replacement rate in the very long run. On the other hand, the steady increase in longevity after WWII in both developed and developing countries is a permanent shock.

#### (3) Time period

Demographic shocks take much longer time compared to other shocks in macroeconomics such as fiscal, monetary, productivity and oil shocks. For example, the transitory fertility shock after WWII took several decades to phase out, and the impacts still continue today because the baby boom generations are retiring over the period of 2010-2030. The persistent mortality decline since WWII increases the life expectancy by 18 years in the past 70 years, and is expected to increase the life expectancy by another 18 years in the next 80 years by 2100. Most studies that project the impacts of demographic change in the future often focus on time periods over 50 to 150 years.

#### (4) Population size

Different fertility and mortality shocks have distinct impacts on population size in both short and long run. For example, in a permanent shock of fertility declines, total population can either expand, remain stable, or shrink in the long run, depending on whether the fertility rate is higher than, equal to, or lower than the replacement rate. A permanent shock of mortality declines increases population size, but tends to have much smaller impacts in the long run compared to fertility shocks.

## 4.3 Baseline scenario

To examine the effects of demographic shocks in open economies, a baseline (or counterfactual or reference) scenario must be chosen. There are four broad strategies in the literature, as presented below. While the first one is unique for open economy models, the other three apply for both open and closed economy models.

#### (1) Autarkic vs open economies

The first one assumes that all economies experience demographic shocks in autarky and then open up to international capital flows for comparison (e.g, Borsch-Supan et al. 2001; Aglietta et al. 2007; Eugeni 2015; Barany et al. 2018).

#### (2) Steady state vs demographic shock

The second one assumes that the world economy is in a steady state in the reference year before demographic shocks occur, and then experiences demographic shocks until reaching a new steady state in the long run. The transition dynamics capture the demographic effects.

#### (3) Transition dynamics vs demographic shock

The third one does not require the world economy to be in a steady state in the reference year, but along a transition path. Many studies based on OLG models assume that the world economy is in a steady state long (such as 150 years) before the time period of interest, so the economy is in transition in the reference year (e.g., Brooks 2003; Borsch-Supan et al. 2006). Liu and McKibbin (2021) also assume that the world economy is not in a steady state in an infinite-horizon model even with a stationary population, but evolves over time towards to a long-run steady state beyond a century, and then introduce demographic shocks on top of the baseline.

**(4) Transition dynamics vs pension reform**

The fourth one, commonly used in the studies on pension reforms, assumes that the transition path driven by demographic shocks in OLG models serves as a baseline scenario, and then introduce various pension policies.

## 4.4 Basic demographics

The introduction of demographics is often associated with a number of life-cycle elements such as birth, death, childhood, retirement, pension systems, age-dependent productivity, elastic labor supply, pension policy, etc. This part focuses on the studies that introduce demographics with minimal departure from infinite-horizon representative-agent models, particularly abstracting from child support and pension systems.

The literature supports that the demographic effect on current account balances depends on the stage of aging processes and on the nature of demographic shocks (Bryant and McKibbin 1998; Faruqee 2002; Feroli 2003; Fehr et al. 2008). On the one hand, if mortality decreases and longevity increases, individuals tend to increase saving to finance consumption over a longer life span. Investment would remain stable if individuals retire at a fixed age and thus labor force does not change. Investment can also increase if individuals do no retire as assumed in the perpetual youth approach, but tends to increase less than saving given labor productivity declines sharply at old ages. Therefore, a permanent mortality shock tends to drive capital outflows. The magnitude would attenuate over time as longevity increases more slowly. On the other hand, if fertility increases above the replacement rate and then converges to the replacement rate in the long run, investment tends to increase initially given labor force increases, while national saving tends to decrease initially given young workers are net borrowers. Thus, capital would initially flow in. Eventually this process would be reversed when the fertility decreases as households consume all their wealth over lifetime. The transitory fertility shock after WWII was even more cyclical in some advanced economies, where fertility first increased, and then decreased well below the replacement level, and is projected to increase to the long-run level. Feroli (2003) points out that in transitory shocks, the current account must be in balance and the net foreign asset position would be reversed to the pre-shock level in the long run as households consume all their wealth over lifetime. This is in contrast with infinitely-lived agent models where the impacts of a transitory shock on the net foreign asset position are not reversed and the annuity value of foreign assets is consumed each period. However, even in temporary shocks, an economy may take one or two centuries to settle in the post-shock steady state, so the current account would be unbalanced over a long time. In permanent shocks, the current account must be in balance in the long run but the net foreign asset position would stay at a constant level. In persistent shocks, the current account is not in balance even in the long run and the net foreign asset position either increases or decreases persistently.

Table 2 collects the demographic studies on international capital flows without child support and pension systems. The first column presents the studies, the second indicates the modeling approach, the third indicates whether the studies model an economy as a small or large open economy, the fourth contains the economies of interest, the fifth is the time periods of results reported in the studies, and the last one indicates whether demographic shocks are real or hypothetical, are fertility or mortality driven or both, and are temporary or permanent. This group of studies assume that individuals are born as workers without experiencing childhood and finance their retirement consumption by accumulating savings without pension systems.

Table 2: Demographic studies without child support and pension systems

| Study | Approach | Size | Region | Period | Demographics |
|---|---|---|---|---|---|
| Faruqee (2002) | Perpetual youth (age-productivity) | Small | US, Japan | 2000-2150 | Fertility & mortality |
| Bryant and McKibbin (2004) | Perpetual youth (age-productivity) | Large | US vs US | 100 years | Hypothetical temporary fertility |
| Borsch-Supan et al. (2001) | OLG | Large | Germany | 2000-2050 | Fertility |
| Henriksen (2002) | OLG | Large | US, Japan | 1970-2050 | Fertility & mortality & migration |
| Feroli (2003) | OLG | Large | G7 | 1970-2000 | Fertility & mortality |
| Domeij and Floden (2006) | OLG | Small | OECD | 1985-2002 | Fertility & mortality |
| Backus et al. (2014) | OLG | Large | US, Japan, Germany, China | 1980-2030 | Fertility & mortality |
| Ferrero (2010) | Perpetual youth (two-stage) | Large | G7 | 1970-2005 | Fertility & mortality |

Faruqee (2002) incorporates demographics into a small open economy model in the perpetual youth approach with an age-productivity profile. The study considers a combination of fertility and mortality shocks with both permanent and transitory components for the United States and Japan over the period of 2000-2150, and shows that the current account can rise or fall in demographic shocks, depending on the stage of the transitions and on the nature of the shocks. Bryant and McKibbin (2004) introduce demographics in Faruqee (2002)'s approach into two representative-agent models: a two-region abridgment of the MULTIMOD model and a two-region abridgment of the G-Cubed model, where the two regions are symmetric and calibrated to the US economy. The study considers an asymmetric demographic shock with one region experiencing a hypothetical transitory baby boom. Although differing on the production side,[1] the two models both show that capital would flow to the baby-boom country in the medium term to finance increased investment driven by the larger labor force.[2]

The impacts of asymmetric demographics on international capital flows can be quantitatively large, indicating that closed-economy models are likely to miss quantitatively important effects. Borsch-Supan et al. (2001) show that capital flows from Germany to other OECD countries due to demographic differences are substantial: German capital exports would exceed 7% of national income around 2020, and then gradually decrease when the baby boom generations begin to consume their retirement saving, reaching 2% around 2035. Capital exports would be even higher at 9% of national income around 2020 if a pension reform of one-third transition to a funded pension system is introduced.

There is a broad consensus that demographic differences can well explain the low-frequency (such as five- or ten-year-average) capital flows between OECD countries over the last quarter of the last century. Henriksen (2002) builds a two-region model for the United States and Japan, and simulates demographic shocks over the period of 1970-2050.[3]

[1]The MULTIMOD model assumes that a single good is produced from capital and labor in each country. The G-Cubed model contains two production sectors for energy and non-energy goods, and output is a function of capital, labor, energy, and non-energy goods. There is an additional sector that creates capital goods which are purchased for investment by both firms and households.

[2]The models show that capital would flow away from the baby-boom country in the short run. The reason is that they differentiate consumption goods by origin of country, and allow the real exchange rate to deviate from one, so the real interest rate does not equal across countries in the short run.

[3]The study assumes that the US experiences a steady decrease in fertility from 1970 to 2020 and remains flat up to 2050, and Japan also experiences a steady increase in fertility from 1970 to 2000 but

The results show that capital flows from Japan to the United States over 1970-2000, but decelerates since 2000 until around 2030 over which Japan's fertility is assumed to increase gradually, and then flows out again until 2050 when its fertility flattens, and eventually flows back to Japan over 2050-2100. The study shows demographic change alone can well explain the current account dynamics between the United States and Japan over the period of 1970-2000. Feroli (2003) shows that the initial effect of a transitory shock on the net foreign asset position is reversed later on as households consume all their wealth over lifetime, leaving no effects in the steady state. In an OLG model of four developed regions comprising G7 countries, the study shows that demographic differences among seven countries can explain some of the long-term capital movements within the group over the period of 1970-2000 and, in particular, demographics alone can well explain the size and timing of the US deficits and Japan's surpluses. Domeij and Floden (2006) build an OLG model where countries differ in productivity and demographics, and show that demographic change can explain a substantial fraction of low-frequency capital flows between OECD countries over 1985-2002. Backus et al. (2014) build an OLG model where countries differ in demographics without productivity differences, capital taxes and retirement policies, and examine the effects of demographics alone on capital flows among the United States, Japan, Germany and China over 1980-2030. They show that demographic differences can well account for the patterns over 1980-2013 for the United States and Japan, and partly for Germany and China. Ferrero (2010) incorporate demographics into a two-region model in Gertler (1999)'s approach, where one region represents the United States and the other is an aggregate region of other G7 countries. The study investigates the contributions of productivity growth, demographics and fiscal policy to the US external imbalances against the group of advanced economies over the period of 1970-2005. The results show that productivity growth plays a dominant role, demographics explain a non-negligible permanent component of the US trade deficit while fiscal policy is of minor importance.

In terms of welfare, the negative consequences of population aging on output and consumption in an open economy are cushioned because the effects are shared with the rest of the world, which can produce sizable welfare gains for domestic residents (Bryant and McKibbin 2004). Capital outflows can partially offset the reduction in rates of return on capital that would otherwise occur in aging countries. While the equilibrium with open capital markets is globally efficient, there are distributional effects within individual economies. Feroli (2003) shows that some agents are made worse off during the transition compared to a closed economy. The first generation of young agents in the baby-bust country would have benefited from closed capital markets as they would have had a higher wage due to the higher capital-labor ratio. Similarly, the generation of older agents in the non-bust country would have been better off with closed capital markets because the rate of return on their savings would not have been negatively impacted by capital inflows. Reversing the argument, open capital markets benefit the old in the bust country and the young in the non-bust country. Krueger and Ludwig (2007) find that young workers gain from higher wages while old asset owners tend to lose in the United States when capital flows from other OECD countries. As population aging affects both population size and structure, Bryant (2004a) argues that the macroeconomic effects of demographic transitions should differentiate aggregate effects and individual effects in per-capita or per-worker terms, particularly for welfare analysis.

is projected to increase from 2000 to 2020 and then to remain flat up to 2050. Both countries experience steady increases in longevity.

## 4.5 Pension systems

The studies without child support and pension systems miss the dependency effects on the consumption side. A strand of the early literature on demographics focuses on the dependency effects, dating back to Coale and Hoover (1958) who propose the dependency hypothesis of a negative link between the young dependency and the aggregate saving rate. Many subsequent empirical studies investigate the effects of youth and/or elderly dependency based on regression analysis, and tend to find large negative effects on saving rates (equivalently, large positive effects on consumption rates).[4] Some studies incorporate such an empirical link into the consumption function in general equilibrium models to examine the demographic effects. For example, Masson and Tryon (1990) incorporate a positive link between the consumption rate and the dependency ratio into the consumption function in the MULTIMOD model of the world economy. The study then examines the effect of population aging in advanced economies on capital flows over the period of 1990-2025, and shows that real interest rates would decrease until around 2010 and then increase afterwards in all countries when the baby boom generations start to retire, and capital would flow from the United States to Germany and Japan. Cutler et al. (1990) introduce demographic structure in the population-weighted Ramsey approach, where demographic transitions change the labor force and also the support ratio. They show that capital would flow from other OECD countries, and the United States responds to demographic change with higher initial consumption in the open economy than in autarky. Floden (2003) follows the same approach of introducing demographics, and argues that since population aging is less dramatic in the United States than in Europe and Japan, capital would move from Europe and Japan to the United States. Capital movements would facilitate the US demographic transition but aggravate the transition in Europe.

It has now become common to explicitly incorporate pension systems in general equilibrium models given they play a pivotal role in financing retirement consumption in many countries. Alternative ways of operating pension systems and managing pension-related public debt can have substantially different macroeconomic outcomes, especially when an economy is fully integrated into the world economy (Bryant and Velculescu 2002; Bryant 2004b). There are five broad ways of operating pension systems: (1) full balance with a constant benefit rate and an endogenous contribution rate (**contribution-balanced**); (2) full balance with a constant contribution rate and an endogenous benefit rate (**benefit-balanced**); (3) full balance with endogenous contribution and benefit rates, where an additional rule is required to govern two endogenous rates (**contribution-and-benefit-balanced**);[5] (4) full balance with constant contribution and benefit rates and an endogenous (labor and/or capital) income tax rate (**tax-balanced**); (5) imbalance where the contribution and benefit rates and the income tax rate all remain constant, and the contribution-benefit gap is financed by government debt over some time period (**unbalanced**).

Table 3 collects the demographic studies with pension systems in open economy models. To consider the role of pension systems in demographic shocks, there are various designs of economic environments and demographic scenarios. In terms of symmetry in demographic change, economic structure, pension systems, and fiscal policy, the studies fall into five strands as below.

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[4]See, e.g., Meredith (1995) for a summary of early empirical studies on Japan.

[5]For example, Bryant (2004b) assume that the contribution rate responds to meet half of the contribution-benefit gap, and the benefit rate responds to meet the other half.

### (1) A small open economy

This strand of the literature considers a small open economy that takes the world interest rate as given and has its own pension system and demographic change. This implicitly assumes the foreign world is stationary without demographic change. Faruqee (2002) considers pension systems in comparison with the case of no pension in a small open economy model of the United States and Japan respectively, where the pension gap is financed through government debt. The study shows that the presence of pension systems tends to reduce national saving and current account balances as fiscal deficits emerge. For Japan, the current account peaks at around 4% around 2030 and reaches -3% around 2100 in the absence of pension systems. In contrast, the current account peaks at around 3% around 2030 and reaches -5% around 2100 in the presence of pension systems. The net foreign liability position differs significantly around 2100, sitting around zero in the case of no pension while around 100% of GDP in the case of pension. Tamirisa and Faruqee (2006) simulate the effects of population aging over the period of 2005-2050 in a small open economy of Czech (representing Europe's aging process) with the pension system unbalanced up to 2020, 2030 and beyond 2050, respectively. The current account increases and peaks at around 5% of GDP over 2025-2030, and then decrease and eventually falls below the baseline around 2045 in the first two cases. In the third case, the current account increases and peaks at around 2.5% of GDP over 2020-2025, and eventually falls below the baseline around 2035. The foreign asset position differs significantly, with around 80% of GDP in the first two cases, and around 25% of GDP around 2030 in the third case.

### (2) Asymmetric pension systems

This strand of the literature assumes that countries are symmetric except pension systems, and demographic shocks are also symmetric. Several theoretical studies show that capital tends to flow from countries with more generous pension systems to countries with less generous systems given identical demographic shocks. Adema et al. (2008) consider asymmetric pension systems in a two-period OLG model of two otherwise identical countries, where one country has a PAYG pension system while the other has a fully funded system. Given an initial integrated equilibrium, the study considers symmetric shocks of permanent mortality and fertility declines, and shows that saving in the funded country rises more than in the PAYG country, leading to capital outflows from the funded country. In addition, the scale of capital flows is smaller in the case of benefit-balanced system compared to the case of contribution-balanced system. Eugeni (2015) builds a similar model, but assumes that the initial state including pension systems is asymmetric across countries, and examines capital flows during the transition dynamics given a symmetric permanent fertility shock. The study shows that countries with less generous pensions tend to save more for retirement, which echos Bernanke (2005)'s global saving glut hypothesis, so capital flows from countries with poor pensions to countries with generous pensions. Barany et al. (2018) show that the autarky interest rate increases in pension generosity, and thus pension asymmetry can drive international capital flows in open economies. This helps explain capital flows from emerging to advanced economies in the last few decades given emerging economies generally have much less generous pension systems.

Table 3: Demographic studies with pension systems

| Study | Approach | Size | Region | Period | Demo-graphics | Pension |
|---|---|---|---|---|---|---|
| Masson and Tryon (1990) | Dependency | Large | G7, other developed, developing | 1990-2025 | Fertility & mortality | No (external dependency) |
| Cutler et al. (1990) | Population-weighted Ramsey | Large | US, other OECD | 1990-2050 | Fertility & mortality | No (external dependency) |
| Floden (2003) | Population-weighted Ramsey | Small | 15 developed | 2000-2150 | Fertility & mortality | No (external dependency) |
| Faruqee (2002) | Perpetual youth (age-productivity) | Small | US, Japan | 2000-2150 | Fertility & mortality | Unbalanced |
| Tamirisa and Faruqee (2006) | Perpetual youth (age-productivity) | Small | Czech | 2005-2050 | Fertility & mortality | Unbalanced |
| Adema et al. (2008) | OLG | Large | Theoretical | Theoretical | Fertility & mortality | Contribution & Benefit vs No |
| Eugeni (2015) | OLG | Large | Theoretical | Theoretical | Fertility | Benefit vs No |
| Barany et al. (2018) | OLG | Large | Theoretical | Theoretical | Fertility & mortality | Contriubtion-Benefit |
| Bryant and Velculescu (2002) | Perpetual youth (age-productivity) | Large | US vs US | Hypothetical | Fertility | Various |
| Bryant (2004b) | Perpetual youth (age-productivity) | Large | US vs US | Hypothetical | Fertility | Various |
| Ito and Tabata (2010) | OLG | Large | Theoretical | Theoretical | Fertility& Mortality | Contribution |
| Faruqee and Muhleisent (2003) | Perpetual youth (age-productivity) | Large | US, Japan, other developed, rest of the world | 2000-2100 | Fertility & mortality | Various |
| Borsch-Supan et al. (2001) | OLG | Large | Germany, rest of EU, rest of OECD | 2000-2100 | Fertility & mortality | Contribution & Benefit |
| Borsch-Supan et al. (2006) | OLG | Large | Germany, France, Italy, rest of EU, North America, rest of OECD, rest of the world | 2002-2100 | Fertility & mortality | Contribution & Benefit |
| Borsh-Supan and Ludwig (2010) | OLG | Large | Germany, France, Italy, US | 2005-2050 | Fertility & mortality | Contribution & Benefit |
| Borsch-Supan et al. (2014) | OLG | Large | Germany, France, Italy, US | 2005-2050 | Fertility & mortality | Contribution & Benefit |
| Fehr et al. (2005) | OLG | Large | US, Japan, Europe | 2000-2100 | Fertility & mortality | Contribution & Gradual privatization |
| Fehr et al. (2008) | OLG | Large | US, Japan, Europe | 2000-2100 | Fertility & mortality & migration | Contribution |
| Pemberton (1999) | OLG | Samll | Theoretical | Theoretical | Fertility & mortality | Balanced |
| Turner et al. (1998) | OLG | Large | US, Japan, Europe, fast-aging OECD, slow-aging OECD | 2000-2100 | Fertility & mortality | Various |
| Tosun (2003) | OLG | Large | Theoretical | Theoretical | Fertility | No (general spending) |

### (3) Asymmetric demographics

This strand of the literature assumes that countries are symmetric, and pension systems are also symmetric, where pension systems can be managed in different ways but are always symmetric in all countries. Bryant and Velculescu (2002) and Bryant (2004b) compare the role of various pension operating schemes in an otherwise identical model given asymmetric fertility shocks. They examine the impacts of fertility declines with alternative pension systems in the MULTIMOD model of two symmetric regions, and show that alternative ways of operating pension systems and managing government debt can have substantially different macroeconomic outcomes especially in open economies. Bryant and Velculescu (2002) consider a transitory fertility decline and recovery over 100 years, and Bryant (2004b) considers permanent fertility declines over 140 years.[6] The results indicate that capital flows away from the shocked economy in all cases of pension systems, but the magnitude differs across cases. Bryant (2004b) shows that the current account balance peaks after half a century and varies from about 1% to 1.5% of GDP across cases, and the net foreign asset position peaks after one century ranging from 45% to 70% of GDP.

Ito and Tabata (2010) build a theoretical OLG model of two countries and focus on the impacts of asymmetric mortality shocks. The model assumes a constant and identical fertility rate across countries, and constant but different mortality rates, and undertakes comparative static analysis of one country's mortality rate in the steady state. They show that the effect of longevity on capital flows in the steady state is not monotone. Higher longevity increases capital outflows when longevity is below a lower bound, but decreases capital outflows when longevity is above the lower bound and below an upper bound , and increases capital inflows when longetivity is above the upper bound. When the pension replacement rate is low, the upper bound tends to be large, so higher longevity would drive capital outflows. When the pension replacement rate is high, the upper bound tends to be small, so higher longevitiy can lead to capital inflows.

### (4) Asymmetric countries, pensions and demographics

This strand of the literature allows countries, pension systems and demographic shocks to be all asymmetric. Most modeling studies calibrate their models to real economies and thus mix all asymmetric factors together. This strand of the literature includes a large group of studies on pension reforms in open economy models, and shows that the effects of pension reforms in closed and open economies can be quite different, and also that various pension policies can have significantly different impacts. Faruqee and Muhleisen (2003) incorporate an age-productivity profile and pension system into the MULTIMOD model of the world economy, and simulate Japan's demographic shock over 2000-2100 relative to a baseline scenario with a stationary population, showing that capital flows out over the entire period with the current account increasing from 0.2% in 2001 to 0.5% in 2025 and then decreasing to 0.3% in 2050. Borsch-Supan and his coauthors develop a series of similar multi-country OLG models to examine the impacts of pension reforms, particularly focusing on Europe. They show that population aging and pension reforms have profound effects on capital markets in Europe. Capital flows from rapidly aging countries to other OECD countries are initially substantial, but the trends would be reversed when the baby

[6] Bryant (2004b) considers two variants of permanent fertility declines: a large cyclical decline and a small gradual decline. The first case assumes that the fertility rate declines sharply, remains at a low level for an extended period, and eventually recovers enough to maintain a stationary population. This fertility shock is roughly analogous to Japan's demographic experience. The second case assumes that the fertility rate declines more slowly and monotonically until the population eventually remains stationary.

boom retirees decumulate savings. This process may be amplified when pension reforms shift public pension provision towards more private funding. Borsch-Supan et al. (2001) focus on Germany, and consider two pension scenarios: the existing system with a constant contribution rate, and a reform of introducing a one-third transition to a funded system. They first consider Germany in autarky, and then consider two open-economy scenarios where capital can flows within the European Union and the OECD. The simulations suggest that capital flows from Germany to the rest of the European Union and OECD would be substantial. Borsch-Supan et al. (2006) improve the above model particularly by allowing elastic labor supply and age-dependent productivity, and extend the geographic coverage to the entire world. They focus on Germany, France and Italy, and consider four capital mobility scenarios: capital flows within the three countries, across the European Union, across the OECD and across the entire world. Capital would flow out from the three countries in the first several decades of this century. The demographic effects on the current account range over 1-3 percent of GDP in 2000 in the three open-economy scenarios, and turn negative by 2030, indicating reversals of capital flows. Borsch-Supan and Ludwig (2010) further distinguish exogenous labor supply at the extensive margin and endogenous labor supply at the intensive margin, and Borsch-Supan et al. (2014) link pension benefits to historical earnings. They examine a set of pension and labor market reforms in Germany, France and Italy, juxtaposed with the United States. They show that capital flows from Europe to the United States are substantial by 2030, with the current account reaching almost 2% of GDP.

Fehr et al. (2005) build a model of three regions (the United States, Europe and Japan), and simulate demographic change over the period of 2000-2100. They show that the demographic transition along with pension tax increases significantly reduces national saving and capital stock, and raises the real interest rate by over 300 basis points by 2050 in Europe. This strong effect on the interest rate is constrast with most studies mainly because the labor endowment is assumed to increase by 1% over generations, which increases effective labor supply by 60% in Europe and strongly offsets the effect of population aging. Capital would flow from the United States towards Europe and Japan given the tax rate increases much less in the United States. They conclude that increasing pension tax rates would worsen the macroeconomic effects of population aging rather than mitigate the fiscal problems. Phasing out the pension system would imposes modest welfare losses on current generations, but generates enormous welfare gains for future generations. Fehr et al. (2008) consider different scenarios of fertility and mortality trends over the period of 2000-2100. In the main scenario, capital would flow from Japan to the United States by 2030, with the current account at 3.5% of GNP, and would reverse in the second half of this century. They argue that future changes in fertility and mortality cannot alleviate the demographic stress. On the one hand, although higher fertility reduces pension tax rates in the long run, it increases government expenditures for education and health in the short and medium run which offsets the positive effect of reduced tax rates. On the other hand, higher longevity has only modest positive impacts on saving rates. Although lower mortality increases the demand for resources during retirement, it implies increases in the future tax rates and declines in unintended bequests, which both tend to reduce individual and aggregate saving. The overall effect of lower mortality on capital stock is relatively moderate, and is much smaller than the impact of fertility trends.

**(5) Asymmetric and coordinated fiscal policy**

Several studies focus on international coordination of pension reforms and, more broadly, fiscal policies. Pemberton (1999) builds an OLG model of a large number of identical small economies, and argues that pension policies are determined on national basis are inefficient compared with international coordination of policies. Suppose that the social welfare function in country $i$ ($i = 1, 2, ..., n$) is denoted by $u_i(\rho_i, r)$ which depends on pension benefits $\rho_i$ and the world interest rate $r$, where $r = r(\rho_1, \rho_2, ..., \rho_n)$. The welfare function increases in $\rho_i$ because pension transfers reduce income inequality, and decreases in $r$ because per capita capital and hence per capita income decreases in $r$. An increase in pension transfers requires an increase in pension taxes, and thus reduces national saving and increase the interest rate, thereby reducing per capita income. The nationally optimal pension rate is determined by

$$\frac{\partial u_i}{\partial \rho_i} + \frac{\partial u_i}{\partial r}\frac{\partial r}{\partial \rho_i} = 0 \tag{52}$$

The globally optimal pension rate is determined by

$$\frac{\partial u_i}{\partial \rho_i} + \frac{\partial u_i}{\partial r}\frac{\partial r}{\partial \rho_i} + \sum_{j=1, j\neq i}^{n} \frac{\partial u_j}{\partial r}\frac{\partial r}{\partial \rho_i} = 0 \tag{53}$$

Comparing the two conditions implies that the nationally optimal rate is higher than the globally optimal rate. This is because national pension policies produce international externalities via their effects on the world interest rate. The study illustrates through a numerical example that the gains from coordination are potentially significant.

Turner et al. (1998) build a model of five regions of OECD countries, and argue that the negative impact of population aging on per capita output can be avoided only through timely and coordinated fiscal consolidation. Coordinated action can produce larger reductions in real interest rates and larger increases in output than could be achieved by individual economies. If only Japan stabilizes public debt, the effects are significantly smaller than in the case of coordinated action. The interest rate in Japan falls 25 basis points by 2050, compared with 50 basis points in the case of OECD-wide action. The current account in Japan increases by more than 2 percent of GDP per annum between 2000 and 2050. The welfare gain in terms of per capita comsumption in Japan increases by 2.2% per annum in coordinated action than in unilateral action. Floden (2003) examines the effects of population aging in 15 developed countries respectievely as small open economies, and also considers the effects of coordinated fiscal balance through increasing tax rates which would decrease the real interest rate by about 80 basis points over the period of 2000-2030.

Tosun (2003) examines the roles of open economy and endogenous fiscal policy in the growth effects of population aging in a two-country OLG model without pension systems. The study focuses on government spending for providing public goods (such as education) which can improve labor productivity. The tax rate is endogenously determined in a median-voter framework. International capital mobility works like a shock absorber, spreading the growth effects of aging globally. On the other hand, endogenous fiscal policy drives countries apart in their transitions by creating asymmetry between their fiscal policies. The two features can change the pattern and the magnitude of the effect of aging on growth, compared to the case of closed economies and exogenous fiscal policies.

## 4.6 Youth dependency

While many empirical studies consider the effects of youth dependency, most modeling studies ignore children in general equilibrium models assuming new cohorts enter economies directly as workers. Several studies argue that the introduction of children has important implications. Higgins and Williamson (1997) examine the effects of youth dependency on national saving and capital flows of Asian economies in a three-stage OLG model (child, worker, and retiree), and find that much of the rise in Asian saving rates since the 1960s can be explained by the decline in the youth dependency ratio. Brooks (2003) builds a four-stage OLG model (child, young worker, old worker, and retiree) for the global economy, assuming that children are not active decision makers and depend on parents for consumption. Young workers allocate their time to raise children and work, and make consumption-saving decisions. However, the analysis does not separate the effects of child support. Bryant et al. (2004) introduce the youth dependency effects in the MULTIMOD model. Introduction of youth dependency generates significantly different inferences about the economic effects in open economies. As lower fertility rates reduce the financial burden on adults, resources are freed for additional consumption and saving. The reallocation of resources changes the transitional dynamics and the ultimate steady state of the economy compared to the case without children. The implications of youth dependency for consumption and saving generate significant effects on external balances. A large fertility decline induces higher saving, part of which goes into increased foreign assets. Thus inferences about the evolution of macroeconomic variables in an open economy and judgments about policy implications and economic welfare can be critically influenced by whether children are explicitly introduced into the analysis. Models that ignore child support miss important aspects of how economies respond to demographic change. In addition, Bryant and Velculescu (2002) show that transfers to the elderly through public pensions and transfers to children from parents often have offsetting effects on key macroeconomic variables. Batsuuri (2021) compares the effects of demographic shocks on external balances with and without childhood in Gertler (1999)'s approach, and illustrates that child dependency changes the impact of fertility transitions on external balances in both short and long run.

## 4.7 Developing countries

Most early studies focus on advanced economies, and show that considerable capital flows can emerge across OECD countries as a result of asymmetric demographic transitions, particularly between the United States on the one side, and Europe and Japan on the other side. Bryant and McKibbin (1998) point out that most open-economy models have paid little attention to developing countries, and the analysis of global dimensions of demographic change needs to consider the saving-investment interactions between industrial and developing economies. Attanasio et al. (2016) also argue that it is important to consider the global economy, made of different regions with different levels of technological progress and factor endowments, especially if the focus is on the impacts under different fiscal policies and pension arrangements.

The cross-border effects can occur not only within OECD countries but also between advanced and emerging economies. As developed countries have been on average aging faster than developing countries, their demographic divergence could stimulate capital flows from OECD countries to emerging economies to finance productive investment. Most studies that include developing economies assume complete capital mobility between advanced and developing economies. This assumption is far from reality, but the studies illustrate potential gains of free capital flows between advanced and developing economies in the context of demographic change.

With complete capital mobility, the pattern of capital flows between developed and developing economies is a natural extension of the pattern among advanced economies with asymmetric demographics. Table 4 collect the demographic studies that incorporate developing countries. This strand of the literature falls into three groups depending on the geographic level. The first group focuses on regions such as advanced and developing regions (or North and South regions) (Attanasio and Violante 2000; Attanasio et al. 2006, 2007, 2016; Bryant 2006, 2007), and the second group selects a set of specific countries mostly including major advanced and emerging economies (Saarenheimo 2005; Fehr et al. 2007, 2013; Backus et al. 2014), and the third group includes the entire world economy which is dividived into a number of countries and regions (Brooks 2003; McKibbin et al. 2004; McKibbin 2005; Aglietta et al. 2007; Marchiori 2011; Liu and McKibbin 2020, 2021). The studies reach a broad consensus of capital flow patterns driven by the baby boom generations. In the last quarter of last century, the retirement saving by aging baby boomers would raise capital supply substantially above investment in Europe, Japan and North America, driving capital flows to emerging Asia, Latin America and Africa. Over the period of 2010-2030, the baby boomers would decumulate their savings for retirement and reverse the capital flow pattern. This shift would be financed by capital flows from emerging Asia and Latin America, while Africa would remain dependent on foreign capital because of continued high population growth. The effects of demographic transitions on developing regions are a mirror image of those on advanced economies. The overall pattern in developing countries is initially dependent on foreign capital, followed by large capital exports towards the end of the transition, reflecting population trends in advanced regions, where aging population would consume down their wealth over retirement. Latin America and emerging Asia would switch to exporting capital around 2010 and continue to increase in the next several decades as the two regions are expected to age more rapidly. Africa would remain dependent on capital imports for longer, reflecting its much lagged aging process.

However, even with complete capital mobility, the pattern of capital flows between advanced and developing countires is not only determined by asymmetric demographic change, but also significantly affected by the difference in pension systems. The above section on pension systems has illustrated the role of pension systems and reforms in international capital flows. Broadly speakding, pension systems are well developed in advanced economies but are much less generous and less broad in developing countries. While pension generosity differs across OECD countries (OECD 2020), the differences are much more considerable bewteen advanced and developing countires (Bloom et al. 2007; Barany et al. 2018). This difference tends to mitigate capital flows from advanced economies to developing countries in the past (Niemeläinen 2021). Looking forward, the pension difference would aggravate capital flows from developing to advanced economies when developing countries age more and save more in the coming decades.

Table 4: Demographic studies on advanced and developing economies

| Study | Approach | Size | Region | Period | Demo-graphics | Pension |
|---|---|---|---|---|---|---|
| Attanasio and Violante (2000) | OLG | Large | North (US & Europe), Latin America | 1950-2100 | Fertility & mortality | No |
| Attanasio et al. (2006) | OLG | Large | Advanced, developing | 1950-2100 | Fertility & mortality | Yes |
| Attanasio et al. (2007) | OLG | Large | Advanced, developing | 2005-2070 | Fertility & mortality | Yes |
| Attanasio et al. (2016) | OLG | Large | High-income, middle-income, low-income, China | 2010-2100 | Fertility & mortality | Yes |
| IMF (2004) (1) | OLG | Large | Advanced & developing | 2000-2060 | Fertility & mortality & migration | Yes |
| Bryant (2006, 2007) | Perpetual youth (age productivity) | Large | Advanced & developing | 2005-2100 | Fertility & mortality | No |
| Gannon et al. (2020) | OLG | Large | Advanced, developing | 2010-2100 | Fertility & mortality | Yes |
| Saarenheimo (2005) | OLG | Large | US, Japan, Europe, China, India | 2000-2050 | Fertility & mortality | Yes |
| Fehr et al. (2007) | OLG | Large | US, Europe Japan, China | 2004-2050 | Fertility & mortality | Yes |
| Fehr et al. (2013) | OLG | Large | US, Japan, Europe, China, India, Northeast Asia | 2005-2100 | Fertility & mortality | Yes |
| Backus et al. (2014) | OLG | Large | US, Japan, Germany, China | 1980-2100 | Fertility & mortality | No |
| Niemeläinen (2021) | OLG | Large | US, China | 1980-2015 | Fertility & mortality | Yes |
| McKibbin et al. (2004) | Perpetual youth (age productivity) | Large | US, Japan, rest of OECD, rest of the world | 1970-2070 | Fertility & mortality | No |
| IMF (2004) (2) | Perpetual youth (age productivity) | Large | US, Japan, rest of OECD, rest of the world | 1985-2100 | Fertility & mortality | No |
| McKibbin (2005) | Perpetual youth (age productivity) | Large | 10 regions of the world | 1985-2100 | Fertility & mortality | No |
| Batini et al. (2006) | Perpetual youth (age productivity) | Large | US, Japan, rest of OECD, rest of the world | 1985-2100 | Fertility & mortality | No |
| Liu and McKibbin (2021) | Perpetual youth (age productivity) | Large | 18 regions of the world | 2015-2050 | Fertility & mortality | No |
| Liu and McKibbin (2020) | Perpetual youth (age productivity) | Large | 18 regions of the world | 2015-2050 | Fertility & mortality | No |
| Brooks (2003) | OLG | Large | 8 regions of the world | 1950-2150 | Fertility & mortality | No |
| IMF (2004) (3) | OLG | Large | 6 regions of the world | 2000-2100 | Fertility & mortality | Yes |
| Aglietta et al. (2007) | OLG | Large | 6 regions of the world | 2000-2050 | Fertility & mortality | Yes |
| Marchiori (2011) | OLG | Large | 10 regions of the world | 2010-2100 | Fertility & mortality | Yes |

As the largest emerging economy, China has drawn significant attention. Most of the above studies incorporate China as an independent economy, and some focus on China particularly. For example, Fehr et al. (2007) add China into Fehr et al. (2005)'s model and show that it would dramatically change capital shortage in advanced economies due to the retirement of the baby boomers. Even though China is aging rapidly, if it maintains high saving rates, restrains public expenditures, and catches up with advanced economies in productivity, China would export capital to the advanced region in the long run. Marchiori (2011) examines the impact of demographic trends on international capital flows in a ten-region OLG model of the world economy, and shows that, over the first half of the century, emerging regions especially China will finance the demand of capital coming from the developed world. In the second half of the century, India will take over this leading position because of the predicted decline in the Chinese labor force. Niemeläinen (2021) extends Ferrero (2010)'s model by introducing pension systems together with elastic labor supply and labor income taxes, and investigates population aging and pension systems as drivers of China's persistent trade surpluses against the United States. China's rapid increase in life expectancy coupled with low pension expenditures helps explain the high saving rate, persistent trade surpluses and large net foreign assets. Although China's high productivity growth has a strong negative impact on the trade balance, the model predicts a positive net foreign asset position and trade balance for most years over the simulation period of 1980-2015.

Capital flows across countries driven by asymmetric demographic change, particularly between developed and developing countries, are overall reciprocal for both groups of economies although there are distributional effects within individual economies. One fundamental difference between the two groups of countries is that capital per worker in developing countries is on average much lower than in developed countries, so capital flows can accelerate capital deepening and boost economic growth in developing countries while developed countries can enjoy higher rates of return on capital. McMorrow and Roeger (2004) is in favor for globalization as a way of countries handling international aspects of aging, arguing that if large capital flows into developing countries could occur, net benefits would accrue to both developed and developing countries and the world could experience an increased convergence in regional income and wealth. Bryant (2004a) argues that the economic openness fosters a partial sharing of demographic shocks with the rest of the world and mitigates the negative consequences of population aging on domestic output and consumption. A large negative demographic shock will cause major negative effects on aggregate output and consumption, but aggregate consumption is significantly above the level that would be experienced in autarky.

However, while emerging economies and developing countries can provide new investment opportunities, they may not be able to absorb substantial OECD savings for several reasons. First, although investment outside OECD brings potential higher rates of return, it requires developing countries to make major improvements in macroeconomic management, contract security and financial stability. Second, developing countries will also experience similar aging processes and the rate of return on capital would also decline eventually, making investment in those regions less attractive over time. For example, China is expected to age rapidly in the next few decades. Third, as baby boom generations in advanced economies are retiring over the period of 2010-2030, they have started to consume their saving.

## 4.8 Factor mobility

Bryant and McKibbin (1998) point out that most modeling studies make assumptions about the mobility of production factors that do not stand up well in comparison with reality. This was still the case in the last two decades. It is often assumed that labor is completely immobile across borders while financial capital is fully mobile across countries. The mobility of consumption goods and capital goods across borders is usually assumed to be intermediate. Attanasio et al. (2016) argue that demographic impacts in an open economy can be reversed or attenuated if the demographic trends are not synchronized across countries, and the effects depend on the relative size of the trends as well as on the institutions that limit or facilitate factor mobility. They point out that much progress is needed to incorporate more realistic factor mobility.

### (1) Capital mobility

The magnitude of capital flows crucially depends on financial openness. In closed economies, national saving and domestic investment must move together. The more open an economy, the more independent the movement of domestic saving and investment. The linkage between the degree of capital mobility and the patterns of national saving and investment has been extensively studied since Feldstein and Horioka (1980) who find a positive but decreasing correlation between domestic saving and investment over time, which indicates a limited but increasing degree of international capital mobility. Taylor (1994) shows that if controlling productivity and demographic effects, the saving-investment correlation suggested disappears, implying that international capital markets may be better integrated than Feldstein and Horioka (1980) indicated. Obstfeld (1995) provides a survey on the empirical tests of capital mobility and concludes that capital mobility between industrial countries appears substantial while much of the developing world still stands outside the international financial markets. Blanchard and Giavazzi (2002) argue that global financial markets have been increasingly integrated not only within OECD countries but also between advanced economies and emerging and developing countries. Even so, the global markets are far from perfect, especially emerging and developing markets. Recognizing Feldstein and Horioka (1980)'s implication, Higgins (1998) argues that the demographic effects on current account balances would be larger for more open economies.

The imperfection of international capital markets has been widely studied since Lucas (1990). Sovereign risk and asymmetric information are two important factors. Portes and Rey (2005) suggest that information asymmetry across countries is a major source of home bias effects and capital flows are affected by both geographic and informational proximity. In the case of pension systems, it implies that households might be more willing to invest their retirement savings in similar countries, such as members of the European Union and OECD, rather than in developing countries. Fehr et al. (2008) include realistic home biases of investment flows, and show that the immediate spillover effects are smaller compared to the case of no home bias.

Several studies consider different scenarios of capital mobility across regions. Borsch-Supan et al. (2001, 2006) assume capital flows at different geographic levels within Germany, France and Italy, within European Union, within OECD, and across the world, in addition to autarkic Germany. Aglietta et al. (2007) consider Europe as an autarky, a small open economy, and a large open economy of the world economy, respectively. This distinction of no capital mobility and full capital mobility illustrates the maximum potential of international capital flows driven by demographic change, but it is not satisfactory for estimating the magnitudes in the intermediate case especially when developing countries are involved. Several other studies introduce country risks or frictions for investment in developing regions as discussed later on.

Another factor that matters for financial capital flows is adjustment costs of physical capital (Bryant and McKibbin 1998). While consumers tend to adjust saving so as to smooth consumption over time, firms also tend to avoid large fluctuations in investment. Lim and Weil (2003) explore the role of capital adjustment costs in a closed economy, and show that larger adjustment costs make consumption less smooth in the face of demographic change than it would be otherwise. In a small open economy, national consumption and saving are highly independent from investment, so capital adjustment costs would dampen the effect of demographic change on internatonal capital flows mainly through the investment channel. However, in a large open economy, demographic change also affects the world interest rate, so capital adjustment costs would also dampen the effect on international capital flows through the consumption channel.

**(2) Labor mobility**

Most studies assume no labor movement across borders except a few exceptions. Fehr et al. (2005) consider immigration in an OLG model of three regions (the United States, Europe and Japan), and show that even a doubling of immigration, which starts in 2001 and continues through 2050, has extremely small effects. Fehr et al. (2004) further consider skill-specific immigration, and still reach discouraging conclusions. If the expansion of immigration is concentrated among low-skilled workers, the fiscal finances of the developed world would deteriorate significantly. The only policy that could help the developed world is to expand high-skilled immigration from the developing world, but this may not be feasible. Henriksen (2002) considers historical immigration as part of demographic change, showing the size is very small compared to total population in the United States, and is even negligible in Japan. Given the economic impacts of realistic immigration are small and massive immigration is subject to political constraints, it is not unreasonable to assume complete labor immobility across countries for modeling convenience.

Fehr et al. (2013) consider offshoring where developed countries hire labor (especially low-skilled) remotely from China and India, and show that such offshoring can significantly affect wage rates of low-skilled labor in developed countries compared to no offshoring. This has different implications on international capital flows. Capital tends to flow into labor-abundant countries to finance productive investment in the case of no offshoring, while capital would flow into labor-abundant countries in the form of remittances in the case of offshoring. However, offshoring may only be feasible in some industries, so the magnitude of remote labor hiring may be limited.

**(3) Goods mobility**

The mobility of goods across countries can be driven from either the demand or supply side. On the production side, the mobility of goods is determined by the tradability of goods across countries. In the dichotomy of tradable and non-tradable goods, non-tradable goods can not be supplied across borders. On the demand side, the mobility of goods can be affected by the preferences between domestic and foreign goods. Most studies assume that there is one homogeneous composite consumption good in the world, which assumes complete substitutability between home and foreign goods and thus complete mobility of goods across countries from a demand perspective.

Bryant and McKibbin (2004) differentiate identical consumption goods produced in two countries by country of origin and then aggregate them into a composite consumption good through a CES aggregator in Armington (1969)'s approach, in contrast with most models assuming a single homogeneous consumption good across countries. This distinction of consumption goods generates different current account dynamics in demographic shocks in the short run because it allows the real interest rate to diverge across countries because of the deviation of the real exchange rate from one. In an extreme case, if individuals only consume domestic goods, then goods are not mobile across countries although the goods are tradable. Bryant and De Fleurieu (2005) undertake sensitivity tests of model parameters that are key determinants of cross-border goods substitutability, including the Armington elasticity. The sensitivity tests suggest that higher substitutability leads to weaker cross-border effects, so empirical estimates of the determinants of cross-border substitutability play critical roles in determining the consequences of demographic shocks.

The mobility of production factors is not independent of the mobility of goods and services. There is a long-established argument that trade in goods and services can be a substitute for movements of factors of production. Therefore, in the context of demographic change, internatioanal capital flows are not only affected by financial openness but also by the mobility of goods and services as well as by the mobility of labor. Helliwell (2004) provides an early review of demographic implications on international flows of capital and labor, and shows that there is evidence of significant demographic effects on both migration and the current account.

## 4.9 Financial frictions

While models without frictions predict that capital would flow from developed countries that are aging more rapidly to developing countries that are relatively young, capital flows in the last several decades present an uphill pattern. As discussed above, the uphill pattern can be partly explained by asymmetric pension systems between advanced and developing economies. In addition, another strand of the literature emphasizes financial frictions as an important determinant of global imbalances. However, most studies incorporate frictions in infinite-horizon agent models. Very few studies introduce financial frictions when linking demographics to global imbalances in life-cycle models. While generic financial frictions matter for demographics-driven capital flows, borrowing constraints of young individuals are directly related to demographic change.

It has been broadly accepted that households tend to smooth their consumption over time since the life cycle hypothesis (Modigliani and Brumberg 1954), but the degree of intertemporal smoothing is in dispute (Bryant and McKibbin 1998). This concerns the degree to which individuals voluntarily wish to smooth consumption, and also to which external constraints such as borrowing constraints prevent individuals from smoothing consumption. Coeurdacier et al. (2015) consider a three-period OLG model (children, worker and retiree) where children do not work but borrow for consumption. They introduce borrowing constraints for children, and show that the autarky interest rate increases in the ease of credit access, and thus differences in the borrowing constraints across countries can drive international capital flows. Barany et al. (2018) build a similar OLG model with asymmetric borrowing constraints and also asymmetric pension systems across countries, and examine the demographic effects on international capital flows. They show that the model can explain a large fraction of capital flows from developing countries to advanced economies given individuals often face more severe borrowing constraints and poorer pension systems in developing countries.

As mentioned above, the international capital market is also far from perfect. Attanasio et al. (2007) introduce transaction costs of investment in developing regions, $\chi(\cdot)$, which is a concave function of positive external wealth of developed regions. More specifically,

$$\chi(b_t) = \begin{cases} \bar{\chi} b_t^{1/2}, & b_t > 0 \\ 0, & b_t \leq 0 \end{cases} \quad (54)$$

where $\bar{\chi}$ is a positive parameter. The study shows that the impacts of the friction on aggregate variables are rather small, mainly because after 2040 the stock of external wealth of the developed region turns negative and the capital market friction becomes irrelevant. Marchiori (2011) considers different scenarios of capital market imperfection which is modeled by a wedge between international and domestic interest rates. More specifically,

$$\tilde{r}_t = r_t(1 + \pi_t) \quad (55)$$

where $\pi_t$ represents the investment risk associated with the institutional quality. If $\pi_t = 0$, there is no investment risk and the above condition reduces to (8). The study shows that a gradual improvement of the country risk in developing regions makes investment more attractive and dampens capital outflows that would finance capital demand from the developed world in the first half of this century.

## 4.10 Structural change

Most models assume a single composite good for both consumption and investment in the world. This abstracts from the change in consumption composition, production structure, the real exchange rate, and the terms of trade. Aglietta et al. (2007) point out that this assumption is a major limitation when examining the demographic effects in the INGENUE model.

Demographic transitions can change economic structure through two channels. On the consumption side, the patterns of consumption across different goods and services (particularly health services) can differ across age. Bryant and McKibbin (1998) argue that change in the composition of consumption bundles over an individual's lifetime may be important. On the production side, as capital and labor intensities can differ across production sectors, the sector shares would change when labor force shrinks. Jin (2012) links the structure of production and international trade to international capital flows. The capital intensity of a country's export and production affects its demand for financial capital, and financial capital inflows into a country can affect its degree of specialization in capital intensive industries. This interaction is important to determine global capital allocation. The study concludes that capital tends to flow towards countries that become more specialized in capital intensive sectors. Faster labor force or productivity growth can lead to capital outflows from labor intensive countries, which helps explain capital flows from emerging to advanced economies in the last several decades.

If there are trade barriers or even non-tradable goods, demograpihc transitions can change the real exchange rate, and thus drive international capital flows through a different channel from the interest rate differentials. Some studies focus on the impacts of population aging on the real exchange rate (Hassan et al. 2011; Groneck and Kaufmann 2017; Giagheddu and Papetti 2020). Bryant and McKibbin (2004) show that the patterns of asymmetric fertility shocks on international capital flows differ in the short and long run because of the movement of the real exchange rate. Liu and McKibbin (2020, 2021) explore demographic change in a six-sector model of the world economy, and show that asymmetric demographic change has different impacts on production sectors within individual economies and thus induce structural change, depending on trade patterns across countries. More specifically, Liu and McKibbin (2020) show that population aging in China, Japan and Korea has significant negative impacts on Australia's energy, mining and durable manufacturing sectors, which are partly offset by positive demographic shocks from emerging Asia (excluding China).

Fehr et al. (2013) include six tradable and non-tradable goods whose production functions differentially use high-, middle-, and low-skilled labor as well as capital. The model allows structural change from both consumption and production sides by introducing age-dependent consumption patterns and factor intensity differentials across sectors, and also allows asymmetric pension systems between advanced and developing economies, and includes productivity catchup where the productivity of developing economies catch up with the US productivity, as well as projected demographic change. The results show that Europe and Northeast Asia including China would run current account surpluses over 2030-2050, while the United States and India would run deficits. However, the study does not explicitly separate the contributions of each mechanism. Papetti (2021b) examines the impact of population aging on the real exchange rate and the current account in an OLG model of multiple countries with two sectors (tradable and non-tradable). The model also allows age-dependent consumption patterns and factor intensity differentials across sectors. As the non-tradable share of consumption expenditures increases in age, more rapidly aging countries tend to produce a higher relative price of nontradables with ensuing structural change on the production side. The model predicts that advanced economies (the United States, Japan, Germany and France) run large current account deficits in the next half century while China runs large surpluses in the next two decades before India takes over China as the largest creditor. The study points out that the global imbalances are mainly driven by asymmetric population aging and pension systems, while the consumption composition channel does not seem to play a key role for capital flows.

## 4.11 Endogenous labor supply

Attanasio et al. (2016) point out that stylized life-cycle models often assume that consumers supply labor inelastically in the sense that they work full time until retirement, then stop working completely, irrespective of the wage rate. This strong assumption is relaxed in some studies, where consumption and leisure both enter in the utility function. The elasticity of substitution between consumption and leisure governs the response of labor supply to the wage rate until retirement. Borsch-Supan et al. (2006) allow endogenous labor supply in an OLG model where pension benefits are earnings-related, and show that workers respond to the decrease in pension benefits not only by increasing savings but also by increasing labor supply. They illustrate that pension reforms can lead to substantial increases in aggregate labor supply, and also affect saving, investment and current account balances. The elasticity of substitution is important in assessing the response of labor supply to pension reforms.

## 4.12 Uncertainty and expectations

Auerbach and Kotlikoff (1987) assume no uncertainty in their model. Since then, various uncertainties have been introduced to OLG models. It is relatively easy to introduce idiosyncratic uncertainty such as uncertainty about life span and uncertainty about individual productivity. However, it is hard to incorporate aggregate uncertainty in general equilibrium models because with aggregate shocks, factor prices are uncertain and depend not only on aggregate supply and demand of capital but also on their distribution in the population (Attanasio et al. 2016).

The degree of consumption smoothing also depends on how individuals' expectations are specified about future dynamics of labor income and wealth (Bryant and McKibbin

1998). Attanasio et al. (2016) argue that, while economic agents are endowed with rational expectations in most models, they might be completely surprised by changes in demographic trends or public policies, in that they do not consider even the possibility of such changes. Backus et al. (2014) assume that households do not have perfect foresight of the entire future price path, but make their decisions based on myopic expectations that future factor prices are equal to the factor prices at the time of decision. They claim that their quantitative results are more robust and transparent than other OLG models with rational expectations because the results do not rely on implausible long-run interest rate and wage paths.

## 4.13 Bequests

The treatment of bequests is also controversial in life-cycle models (Bryant and McKibbin 1998). There are two types of bequests: unintended and intended, where unintended bequests occur because agents face uncertainty of life span while intended bequests are motivated by agents caring their offspring. Unintended bequests are often introduced in two alternative approaches (Henriksen 2002). One is to assume that there is a perfect annuity market so that each agent writes a contract with the members of her own cohort that make the survivors share the wealth or debt of those who die prematurely (Blanchard 1985; Rios-Rull 2001; Storesletten et al. 2004). This insurance mechanism eliminates the risk of leaving accidental bequests for individuals. The other approach assumes no insurance mechanism but divides aggregate bequests equally among all survivors. On the other hand, intended bequests are introduced in a straightforward way that bequests enter in the utility function additively (Domeij and Floden 2006). Generally speaking, with intended bequests, life-cycle models and infinitely-lived agent models would more align with each other. However, there appears no study that investigates the role of different bequest treatments in the demographic effects on national saving and investment, and hence on international capital flows.

## 4.14 Country size

The magnitude of capital flows heavily depends on the relative size of countries (or populations). Population size affects capital flows through two channels: one is the population scale and the other is the interest rate change.

### (1) Population scale

A small open economy has little impact on the global interest rate and its domestic investment moves independently from domestic saving over demographic transitions. For small open economies with different population sizes, the global interest rate remains constant, so the current account in terms of output is independent from absolute population size, as indicated by (38). Output in a small open economy linearly increases in worker size and, if assuming age structure is stationary, also linearly increases in population size. This implies that the current account per capita remains constant, so the national current account linearly increases in population size. This scale effect matters for the magnitude of international capital flows. However, it is often more relevant to focus on the current account in terms of GDP, which is independent from population size in a small open economy.

#### (2) Interest rate change

Demographic shocks in a large economy can change the world interest rate. For a given demographic transition, the larger an open economy, the greater its impact on the global interest rate and the closer domestic saving and investment must move together. The interest rate change generally tends to dampen capital flows per capita compared to the case of a small open economy.

# 5 Empirical studies

Apart from general equilibrium models, many empirical studies examine the demographic effects on savings, investment, and current account balances in econometric models based on cross-country macroeconomic data. This section first discusses the approaches of incorporating demographic structure in econometric models, and then review the studies based on regression analysis, followed by the studies based on panel vector auto-regressive (VAR) models.

## 5.1 Demographic variables

Introducing demographic variables into econometric models involves several issues: (1) the representation of age structure; (2) the interaction between demographic variables and other variables; (3) the relative change of demographic structure.

#### (1) Dependency ratio vs age distribution

There are two broad approaches to constructing demographic variables in econometric models. The most common one is the (young and/or elderly) dependency ratio. The dependency variables are simple and intuitive. However, the approach implicitly assumes that working-age population are homogeneous and thus misses the age-distribution effects within workers given there is strong life-cycle productivity. The second one is to use a low-order polynomial to represent the entire age-distribution (Fair and Dominguez 1991). This approach incorporates the entire age distribution and meanwhile avoids the issue of correlation between the shares of different age groups (see Appendix B for more details).

#### (2) Independent vs interactive terms

Most empirical studies include demographic variables independently without interacting with other variables. Mason (1988) develops a variable-rate-of-growth model of the link between the youth dependency ratio and the national saving rate, and argues that given positive labor productivity growth, younger cohorts enjoy higher permanent incomes and higher consumption than their elders. The model suggests that the saving rate depends on the product of the youth-dependency ratio and the growth rate of national income in addition to the dependency ratio alone. This interactive relationship is captured in (35). Moreover, this interaction also contributes to the national investment rate as indicated in (37) and hence to the current account as indicated in (38). Some empirical studies therefore incorporate such an interaction term in their regressions (e.g., Higgins 1998).

**(3) Absolute vs relative change**

It is relative demographic change of one country compared to others, rather than absolute demographic change, that drives international capital flows. This has been emphasized in many modelling studies, but has often been overlooked in empirical studies. Some empirical studies express demographic variables relative to their sample averages (Chinn and Prasad 2003; Luhrmann 2003; Jaumotte and Sodsriwiboon 2010). In particular, IMF (2019b) incorporates not only demographic variables but most other variables in the form of deviations from the GDP-weighted sample average. However, no studies compare the results of absolute and relative changes in an otherwise identical econometric specification.

## 5.2 Regression studies

Empirical studies on the macroeconomic impacts of demographic change date back to Coale and Hoover (1958). They propose the dependency hypothesis of a negative link between the young dependency ratio and the aggregate saving rate. Many subsequent empirical studies find strong evidence for the hypothesis (see, e.g, Meredith 1995 for a review of early studies). Higgins and Williamson (1997) show that much of the rise in Asian saving rates since the 1960s can be explained by the decline in youth dependency burdens. But these studies miss the investment side in the sense that they do not consider the differences in savings and investment of open versus closed economies. The omission of the demand for capital leads to biases in the estimation of demographic effects on savings because the estimation also picks up demographic effects on investment. Saving and investment can be identified separately only when countries can borrow and lead on the international capital markets without constraints and at the given world interest rate (Higgins and Williamson 1997). If one focuses on the current account which is the residual between national saving and investment, the estimation bias would disappear in principle (e.g., Higgins 1998).

Table 5 collects regressions studies on the current account determinents. Such studies often include demographic structure as explanatory variables although many of them do not focus on demographics. Most studies include both advanced (or developed or industrial) and developing countries in their samples. The first column presents the studies, and each study occupies two rows: the first row matches columns 2-5, and the second row presents other independent variables (excluding demographic variables) in the regressions. The second column indicates the sample size, the third one the time period of data, and the fourth one indicates whether the estimations are cross-sectional, panel, or both. The fifth column indicates whether demographic variables are introduced as polynomials or dependency ratios, and also whether demographic variables are expressed in absolute or relative terms. The last three columns present the estimation coefficients on different age groups. To facilitate interpreting the estimation results consistently across studies, some additional information is presented below.

(1) For the studies incorporating the dependency ratios, the sixth and seventh columns represent the youth and elderly dependency ratios respectively. There are two exceptions: IMF (2004) uses the shares of working-age population and elderly population in total population, and Dao and Jones (2018) use the elerly dependency ratio and the share of working-age population in total population. The two columns are merged if the combined dependency ratio is used such as Debelle and Faruqee (1996).

(2) For the studies incorporating the entire age structure, the last three columns represent the share of each group in total population. The studies that construct demographic structure in the polynomial approach do not present the coefficients on the three age groups, but on each five-year-interval age group, so we only present the signs of the results.

(3) Given some studies report a set of results for different samples and in different estimation methods, we use "A" for advanced countries, "D" for developing countries, "F" for all countries, and "S" for cross-sectional estimation and "P" for panel estimation.

(4) In terms of statistic significance, we use *, **, *** and IS to indicate the significance level of 10%, 5% and 1%, and insignificance, respectively.

(5) All studies run regressions for current account balances (in terms of GDP) except that Lane and Milesi-Ferretti (2001) focus on net foreign assets (cummulated current account balances).

Table 5: Studies on current account determinants in regressions

| Study | Sample | Period | Method | Demographics | Youth | Elderly | Worker |
|---|---|---|---|---|---|---|---|
| Debelle and Faruqee (1996) | 21 advanced & 34 developing | 1971-1993 | Section & Panel | Relative dependency | -0.18**~-0.20**(AS)<br>-0.04*~-0.05**(DS)<br>-0.025**(AP) | | NA |
| | Relative per capita GDP, fiscal variables, terms of trade, capital-output ratio, capital control, net foreign assets, inflation, real interest rate, capital per worker | | | | | | |
| Chinn and Prasad (2003) | 18 advanced & 71 developing | 1971-1995 | Section & Panel | Relative dependency | -0.057(AS)<br>-0.060*(DS)<br>-0.054*(FS)<br>-0.108*(AP)<br>-0.055*(DP)<br>-0.025(FP) | 0.195(AS)<br>0.156(DS)<br>-0.173(FS)<br>-0.109(AP)<br>-0.138(DP)<br>-0.051(FP) | NA |
| | GDP growth, fiscal balance, relative income, financial deepening, terms of trade, openness, capital control | | | | | | |
| Calderon et al. (1999) | 44 developing | 1966-1995 | Panel | Absolute dependency | -0.112 | -0.019 | NA |
| | GDP growth, private saving, public saving, exports, real exchange rate, terms of trade, black market premium, capital control, GDP growth of advanced economies, real interest rate, inflation, liabilities, external debt | | | | | | |
| IMF (2004) | 21 advanced & 94 developing | 1960-2000 | Panel | Absolute dependency | NA | -0.25* | 0.05* |
| | Income level, fiscal balance, net foreign assets, financial deepening, terms of trade, openness, oil-exporting dummy | | | | | | |
| Gruber and Kamin (2007) | 22 advanced & 44 developing | 1982-2003 | Panel | Absolute dependency | -0.026* | -0.112* ~ -0.153* | NA |
| | Relative income, GDP growth, fiscal balance, net foreign assets, openness, banking crises, institution quality | | | | | | |
| Ito and Chinn (2007) | 19 advanced & 70 developing | 1986-2005 | Panel | Relative dependency | 0.028(A)<br>-0.012(D) | 0.07**(A)<br>-0.016(D) | NA |
| | Financial deepening, financial openness, institution quality, net foreign assets, relative income, terms of trade, output growth, trade openness, oil exporting dummy | | | | | | |
| Lee et al. (2008) | 54 countries | 1973-2004 | Panel | Relative dependency | NA | -0.12** ~ -0.23** | NA |
| | GDP growth, relative income, population growth, fiscal balance, net foreign assets, oil balance, banking crisis, financial center dummy | | | | | | |
| Ca'Zorzi et al. (2009) | 87 countries | 1980-2004 | Panel | Relative dependency | -0.02 | -0.224* | NA |
| | GDP growth, relative per capita GDP, population growth, fiscal balance, trade openness, financial openness, net foreign assets, investment, oil balance, institution quality | | | | | | |
| Jaumotte and Sodsriwiboon (2010) | 49 countries | 1973-2008 | Panel | Relative dependency | NA | -0.158* | NA |
| | Per capita GDP growth, relaitve per capita income, population growth, net foreign assets, oil balance, financial openness, financial center dummy, euro dummy | | | | | | |
| Brissimis et al. (2012) | Greece | 1960-2007 | Time series | Absolute dependency | IS | IS | NA |
| | Relative per capita GDP, real exchange rate, investment, credit, real interest rate, inflation volatility | | | | | | |
| Dao and Jones (2018) | 49 countries | 1986-2016 | Panel | Realtive dependency | NA | -0.044** ~ -0.074*** | 0.132*** ~ 0.198*** |
| | Population growth, life expectancy | | | | | | |
| Coutinho et al. (2018) | 65 countries | 1987-2016 | Panel | Relative dependency | NA | -0.047* | NA |
| | 25 variables (relative per capita income, population growth, aging speed, manufacturing share, oil balance, mining export, reserve currency share, financial centre dummy, etc.) | | | | | | |

Table 5: Studies on current account determinants in regressions (continued)

| Study | Sample | Period | Method | Demographics | Youth | Elderly | Worker |
|---|---|---|---|---|---|---|---|
| IMF (2019b) | 21 advanced & 28 developing | 1986-2016 | Panel | Relative dependency | NA | -0.069 | 0.138** |
| | 21 variables (cyclical, macroeconomic, structural, policy) | | | | | | |
| Higgins (1998) | 23 advanced & 77 developing | 1950-1989 | Section & Panel | Absolute polynomial | - | - | + |
| | Per worker GDP growth, relative price of investment | | | | | | |
| Bosworth and Keys (2004) | 88 countries | 1960-1999 | Section & Panel | Absolute polynomial | - | - | + |
| | GDP growth | | | | | | |
| Luhrmann (2003) | 121 countries | 1970-1997 | Panel | Relative polynomial | - | - | + |
| | GDP growth, capital control, income and capital tax, tariffs, financial deepening, institution quality, education | | | | | | |
| Han and Shin (2018) | 34 OECD | 1980-2015 | Panel | Absolute polynomial | - | - | + |
| | GDP gap, GDP gap of trading partners, fuel exports, fuel imports, income level, GDP growth, openness, net foreign assets, fiscal balance, real exchange rate | | | | | | |
| Eugeni (2015) | 126 countries | 2011 | Section | Absolute dependency | -0.18***∼-0.20*** | | NA |
| | Per capita GDP, per capita GDP growth, pension coverage, financial deepening, investment, fiscal balance | | | | | | |
| Lane and Milesi-Ferretti (2001) | 21 advanced & 45 developing | 1970-1998 | Panel | Absolute polynomial | -1.47(AP) -1.01(DP) -1.2(FS) | -0.66(AP) -0.522(DP) -0.44(FS) | + |
| | Per capita GDP growth, fiscal debt | | | | | | |

Coutinho et al. (2018) divide the current account determinants into two broad groups: fundamental and non-fundamental factors. IMF (2019b) futher organizes the determinants into four groups: macroeconomic fundamentals, structural fundamentals, policy variables and cyclical factors. Demographics is one of the structural fundamentals. The empirical studies reach a strong qualitative consensus that the demographic change since the second half of last century has statistically significant effects on the current account balance. More specifically, the current account tends to decrease in the young and/or elderly dependency ratio, and tends to increase in the working-age population share. Quantitatively, there is also a broad consensus that most estimates for the dependency ratios rougly range from -0.05 to -0.25. This indicates that 4-20 percentage points of the dependency ratio (without differentiating absolute and relative ratios) leads to current account deficits of one percentage point of GDP.

While there is a broad quantitative consensus on the demographic effects, the studies differ in the magnitude of the effects and the level of significance. Debelle and Faruqee (1996) find that 5 percentage points of the dependency ratio above the average leads to a current account deficit of one percentage point of GDP. Chinn and Prasad (2003) find similar quantitative effects, but the elderly dependency ratio is not significant. Gruber and Kamin (2007) undertake similar panel regressions but with absolute dependency ratios, and find similar quantative effects with both dependency ratios significant. IMF (2004) finds a similar effect of the share of elderly population, and a positive effect of the share of working-age population. Ito and Chinn (2007) investigate the impacts of fiscal balances, financial development and openness on global imbalances, and find that the dependency ratios are generally not significant. Calderon et al. (1999) focus on developing countries, and show that the dependency ratios are not significant as the private saving rate is included as an explanatory variable, indicating that the dependency ratio does not affect the current account beyond its effect through private saving.

The differences in the results are attributed to a number of factors including samples, time periods, data frequency, estimation methods, demographic variables, and non-demographic variables. In terms of samples, almost all studies include advanced economies, but differ in the set of developing countries. As to time periods, most studies focus on 1970 onwards due to data availability especially for developing countries. The studies use either annual, five-year-average, ten-year-average, or even entire-period-average data, or different frequencies for comparison.

In terms of estimation methods, the studies use cross-sectional and/or panel regressions to characterize the variation of the current account across countries and over time. Debelle and Faruqee (1996) show that the dependency ratio is significant with a negative sign in the cross-sectional regressions but is generally insignificant in the panel regressions. Higgins (1998) finds that the age-distribution coefficients are significant in both panel and cross-sectional regressions, and are similar in both qualitative and quantitative terms. Bosworth and Keys (2004) find that the age-distribution coefficients are larger in the cross-sectional regressions than in the panel regressions. Chinn and Prasad (2003) show that the coefficients are generally smaller in absolute value in the panel regressions compared to the cross-sectional regressions. These studies suggest that demographic factors play a more important role in low-frequency rather than high-frequency current account variation.

The differences of demographic variables directly contribute to the differences in the results. However, no studies compare different representations of demographic structure, such as dependency ratios and age distributions, absolute and relative demographic changes, in an otherwise identical econometric specification. Higgins (1998) introduces age structure in the polynomial approach, and incorporates an interaction term of demographic and growth variables. The study focuses heavily on demographic factors but less on other determinants. The results suggest strong demographic effects on both saving and investment and also on current account balances, indicating that access to surplus foreign savings has provided an important buffer, allowing some of the youth dependency burden to be reflected in negative current account balances rather than lower domestic investment. Luhrmann (2003) improves Higgins (1998)'s analysis in three aspects. First, the paper argues that the expectation of future demographic change can affect current international capital flows, and thus incorporate both current and future demographic change in the regressions. Second, it is demographic differentials across countries rather than demographic structure in own country that affect international capital flows, so the paper defines the dependency ratios in relative terms to ensure that the estimated demographic effects on current account balances sum to zero across the global sample of countries. Third, the paper considers a set of other independent variables that can affect international capital flows. However, Luhrmann (2003) also incorporates a number of additional independent variables, and does not isolate the effect of the improvements on the demographic variables.

Turning to non-demographic variables, comparing independent variables across studies suggests that most studies include some common variables such as GDP growth, fiscal balance, trade openness and terms of trade in addition to demographics. But even for GDP growth, the studies may use different measures such as economy-wide GDP growth, per capita GDP growth, per worker GDP growth, and relative per capita GDP. Most studies also incorporate financial development, capital control and institutional quality, but the measures for each variable may also differ across studies. Apart from a set of common variables, the studies significantly differ in other variables such as initial net foreign assets, real interest rates, real exchange rates, inflation rates, oil-exporting country dummies, financial center dymmies, etc. The difference in selecting other variables depends on the focus of the studies. For example, Higgins (1998) heavily focus on demographic variables and miss other common variables, Ito and Chinn (2007) focus on the financial development, and Eugeni (2015) includes pension variables. Calderon et al. (1999) focus on developing countries, and hence incorporates some variables that are unique for developing countries such as black market premium on foreign exchange rates, GDP growth of advanced economies, and external debt. The selection of other variables also depends on the focus of time horizon. Some studies such as Chinn and Prasad (2003) focus on long-term determinants and exclude cyclical factors, and use five-year and even longer-period averages of data to smooth out short-term variations. Coutinho et al. (2018) and IMF (2019b) focus on both short-term cycles and long-term trends of the current account, and thus include both short- and long-term determinants in the regressions based on annual data.

Several studies focus on the role of pension systems in addition to demographic structure. Bloom et al. (2007) show that life expectancy has no effects on national savings rates in the absence of pension systems and retirement restrictions. But if there are retirement incentives (e.g., pension benefits are only payable on retirement or are conditional on an earnings test), an increase in life expectancy tends to push up savings rates, as expected from the need to finance a longer retirement. But the effect disappears if there are pension systems with high replacement rates because the need for income in retirement is provided by pension systems. Eugeni (2015) finds that the higher is the percentage of the working population covered by the pension system, the lower are savings and the current account balance. The analysis implies that an improvement of the pension system in China would have the effect of reducing the imbalances.

Lane and Milesi-Ferretti (2001) focus on net foreign asset positions rather than current account balances directly, and find strong support for the demographic effects on international capital flows. A decline in the net foreign asset occurs if there is an increase in the population shares of younger age cohorts, whereas the net foreign-asset position responds positively to an increase in the share of workers nearing retirement, with a maximum effect for the 50-54 age group. The over-65 age group exerts a negative effect, consistent with the running down of net foreign assets. The demographic effect on the net foreign-asset position is more sensitive in developing countries, but the statistic significance is weaker.

### 5.3 VAR studies

Two studies use panel VAR models to examine the demographic effects. The advantage of VAR models is to allow dynamics in nature compared to regressions. Kim and Lee (2007) examine the demographic effects on national saving and current account balances in East Asia over the peroid of 1981-2003. The model includes the dependency ratio, GDP growth, the saving rate, the current account, and the real interest rate as variables in order. The study shows that an increase in the dependency ratio, especially the elderly dependency ratio, significantly lowers the saving rate and subsequently worsens current account balances. They also project that the future population aging in East Asia would have a significant impact on global capital flows and current account imbalances. Kim and Lee (2008) undertake a similar study of G7 countries over the period of 1979-2001 and also find substantial demographic effects on national saving and current account balances.

## 6 Conclusion

Population has been aging globally, and is expected to age more rapidly in the next few decades. The asymmetry in the timing and speed of demographic transitions across countries, especially between developed and developing regions, has important implications on international capital flows and current account balances. This paper has presented a small open economy model to illustrate the demographic effects on international capital flows. The model ensures an analytical solution which links a large number of factors to the current account transparently, and hence enables tractable analysis of both transition dynamics and steady states of any demographic shocks especially temporary shocks. Starting from the model, the paper has provided a comprehensive review of the modeling and empirical studies in the literature.

There are several qualitative implications. First, the patterns of capital flows depend on the nature of demographic shocks: (1) fertility or mortality: higher longevity tends to increase national saving and drive capital outflows; lower fertility tends to increase per-worker saving due to less child support, but decrease national saving, and decrease national investment even more, resulting in capital outflows; (2) permanent or transitory: a permanent shock tends to change the net foreign asset position in the long run while a transitory shock has no impacts on the long-run position with initial capital flows being reversed when the shock disappears. Second, the patterns of capital flows also depend on the stage of demographic shocks because foreign assets accumulated early in life would be decummulated later for retirement in a finite horizon of life. Third, less generous pension systems tend to increase national saving and drive capital outflows. Fourth, financial frictions such as borrowing constraints of young people also tend to increase national saving and drive capital outflows. Fifth, production and trade specialization in labor-intensive sectors tend to decrease investment and drive capital outflows. Sixth, the magnitude of the demographic effects also depends on the extent of cross-border mobility of capital, labor and goods.

There are also several quantitative implications. First, demographics alone can explain a significant fraction of historical current account dynamics especially low-frequency movements among advanced economies in the last quarter of last century. Second, institutional and financial frictions need to be incorporated to reconcile the demographic effects with historical capital flows from emerging to advanced economies. Third, production structure and trade specialization also play an important role in the demographics-driven capital outflows from emerging economies.

The empirical studies reach a strong qualitative consensus that the demographic change since the second half of last century has statistically significant effects on the current account balance. The current account tends to decrease in the young and/or elderly dependency ratio, and tends to increase in the working-age population share. There is also a broad quantitative consensus on the demographic effects, while the studies differ in the magnitude of the effects and the level of significance. The differences are attributed to a number of factors including samples, time periods, data frequency, estimation methods, demographic variables, and non-demographic variables.

There are several aspects to be further explored in the future. First, imperfect capital mobility is important for estimating international capital flows. The dichotomy of complete mobility and immobility is not satisfactory for quantifying the demographic effects. Second, demographics-related and more generic financial frictions on both domestic and international capital markets need to be explored. Financial frictions have drawn significant attention in macroeconomic research especailly since the global financial crisis, but have not been much linked to demographic studies. Third, cross-border substitution of consumptionn goods from both production and consumption sides merits further investigation, which requires disaggregate consumption goods in general equilibrium models. Fourth, demographics-driven structural change from both consumption and production sides in open economies is a promising area, which also calls for multiple-sector models.

Fifth, while the concern about the assumption of rational expectations is legitimate especially given demographic change is a long-term low-frequency process, it is challenging to deal with non-rational expectations in a conceptually consistent manner.

# Appendix

## A. The modeling approaches

### (1) The perpetual youth approach

There are several variants of the perpetual youth approach (Blanchard 1985; Gertler 1999; Faruqee 2002).

### (a) Blanchard's approach

Consider continuous time. Denote by $c(s,t), y(s,t), w(s,t), h(s,t)$ consumption, non-interest income, non-human wealth and human wealth as of time $t$ of an individual born at time $s$. The consumer maximizes lifetime utility

$$U_s = \int_s^{\infty} ln[c(s,v)]exp\{(\beta + p)(s - v)\}dv$$

$$s.t. \qquad \int_s^{\infty} c(s,v)exp\left\{-\int_s^v [r(\mu) + p]d\mu\right\}dv = w(s,t) + h(s,t)$$

The optimal consumption is therefore a linear function of total wealth.

$$c(s,t) = (\beta + p)[w(s,t) + h(s,t)]$$

### (b) Faruqee's approach

Consider continuous time. Denote age-independent birth and mortality rates by $b(t)$ and $p(t)$ respectively. Total population at time $t$ is

$$N(t) = exp\left\{\int_0^t [b(v) - p(v)]dv\right\}$$

Assuming individuals are born as new workers, the effective labor supply at time $t$ of an individual born at time $s$ is

$$l(s,t) = e^{\mu t}\left[a_1 e^{-\alpha_1(t-s)} + a_2 e^{-\alpha_2(t-s)} + a_3 e^{-\alpha_3(t-s)}\right]$$

where $\mu$ represents the rate of labor productivity growth, and $a_1, a_2, a_3, \alpha_1, \alpha_2, \alpha_3$ are parameters that govern a hump-shaped productivity profile over age. The aggregate effective labor supply is

$$L(t) = \int_0^t n(s,t)l(s,t)ds$$

where the size of the cohort born at time $t$ is $n(t,t) = b(t)N(t)$.

### (c) Gertler's approach

Consider discrete time. Each individual is born as a worker. Conditional on being a worker in the current period, an individual remains a worker in the next period with a probability of $q$, and retires with a probability of $1-q$. Conditional on being retired in the current period, an individual remains retired in the next period with a probability of $p$, and die with a probability of $1-p$. This approach extends an individual's life cycle from two states (worker and death) in Blanchard (1985)'s approach to three states (worker, retiree and death).

### (2) The dependency approach

The consumption function of a representative individual after incorporating the dependency link is as follows:

$$c_t = (\beta + p + \alpha\delta)\omega_t$$

where $c_t$ represents aggregate consumption, $\omega_t$ is total wealth consisting of human wealth and financial wealth, $\beta$ is the rate of time preference, $p$ is the mortality rate (independent of age), $\delta$ is the dependency ratio and $\alpha$ is the coefficient estimated from the regression.

### (3) The population-weighted Ramsey approach

Consider the following social welfare function where individual utility is summed over population:

$$U = \int_0^\infty e^{-\beta t} P_t u(c_t) dt = \int_0^\infty e^{-\beta t} \frac{N_t}{\alpha_t} u(c_t) dt$$

where $P_t$ denotes population size, $N_t$ labor force, $\alpha_t = N_t/P_t$ the support ratio, $c_t$ per capita consumption, and $\beta$ the rate of time preference. The per-capita budget constraint implies

$$\dot{k}_t = f(k_t) - \frac{c_t}{\alpha_t} - n_t k_t$$

where $n_t$ denotes the growth rate of labor force. This approach modifies the standard Ramsey model by introducing the support ratio $\alpha_t$ in both the utility function and the budget constraint.

## B. The polynomial approach

Consider a regression model

$$y_t = \beta_0 + \beta_1 X_t + \alpha_1 p_{1,t} + \alpha_2 p_{2,t} + ... + \alpha_J p_{J,t} + \mu_t$$

where $y_t$ is the dependent variable, $X_t$ is a vector of explanatory variables, and $p_{1,t}, p_{2,t}, ..., p_{J,t}$ represent the shares of $J$ age groups in total population respectively. It is not sensible to estimate $J+1$ unconstrained coefficients because the age shares are highly correlated. We constrain the coefficients of the population shares to lie along a third-order polynomial such that

$$\alpha_j = \gamma_0 + \gamma_1 j + \gamma_2 j^2 + \gamma_3 j^3$$

We can rewrite the regression as

$$y_t = \beta_0 + \beta_1 X_t + \gamma_0 \sum_{i=1}^{J} p_{j,t} + \gamma_1 \sum_{j=1}^{J} j p_{j,t} + \gamma_2 \sum_{j=1}^{J} j^2 p_{j,t} + \gamma_3 \sum_{j=1}^{J} j^3 p_{j,t} + \mu_t$$

We impose an additional restriction that the coefficients of the age distribution variables sum up to zero such that

$$\sum \alpha_j = 0$$

This implies the following relationship

$$\gamma_0 J + \gamma_1 \sum_{j=1}^{J} j + \gamma_2 \sum_{j=1}^{J} j^2 + \gamma_3 \sum_{j=1}^{J} j^3 = 0$$

This gives us

$$\gamma_0 = -\frac{\gamma_1}{J}\sum_{j=1}^{J} j - \frac{\gamma_2}{J}\sum_{j=1}^{J} j^2 - \frac{\gamma_3}{J}\sum_{j=1}^{J} j^3$$

The final regression becomes

$$\begin{aligned} y_t &= \beta_0 + \beta_1 X_t + \gamma_1 \left(\sum_{j=1}^{J} j p_{j,t} - \frac{1}{J}\sum_{j=1}^{J} j\right) + \gamma_2 \left(\sum_{j=1}^{J} j^2 p_{j,t} - \frac{1}{J}\sum_{j=1}^{J} j^2\right) \\ &\quad + \gamma_3 \left(\sum_{j=1}^{J} j^3 p_{j,t} - \frac{1}{J}\sum_{j=1}^{J} j^3\right) + \mu_t \\ &= \beta_0 + \beta_1 X_t + \gamma_1 D_1 + \gamma_2 D_2 + \gamma_3 D_3 + \mu_t \end{aligned}$$

where

$$D_1 = \sum_{j=1}^{J} j p_{j,t} - \frac{1}{J}\sum_{j=1}^{J} j, D_2 = \sum_{j=1}^{J} j^2 p_{j,t} - \frac{1}{J}\sum_{j=1}^{J} j^2, D_3 = \sum_{j=1}^{J} j^3 p_{j,t} - \frac{1}{J}\sum_{j=1}^{J} j^3$$

Once we estimate $\gamma_1, \gamma_2, \gamma_3$, we can calculate $\gamma_0$, and then calculate $\alpha_j$.

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