Demographic Change, National Saving and International Capital Flows: A Tractable OLG Model

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Abstract

This paper explores the impacts of demographic change on national saving and international capital flows. Introducing demographic structure and pension systems into a four-stage overlapping-generation model of a small open economy, the paper derives analytical solutions which link a wide range of factors to national saving and the current account. This framework enables tractable analysis of the effects of various demographic shocks on national saving and external balances, and also of the interaction between demographic shocks and productivity growth and pension systems. The demographic impacts on national saving and capital flows depend on the nature of demographic shocks (fertility or mortality; transitory, permanent or persistent) and on the stage of demographic shocks, as well as productivity growth and pension structure. The paper further applies the model to four economies (the United States, Japan, China and India) to project the demographic impacts on external balances over this century.

Keywords: Global demographic change; fertility and mortality; international capital flows; current account balances; overlapping generation model; pension systems
JEL Codes: E21, E44, F21, F41, J11

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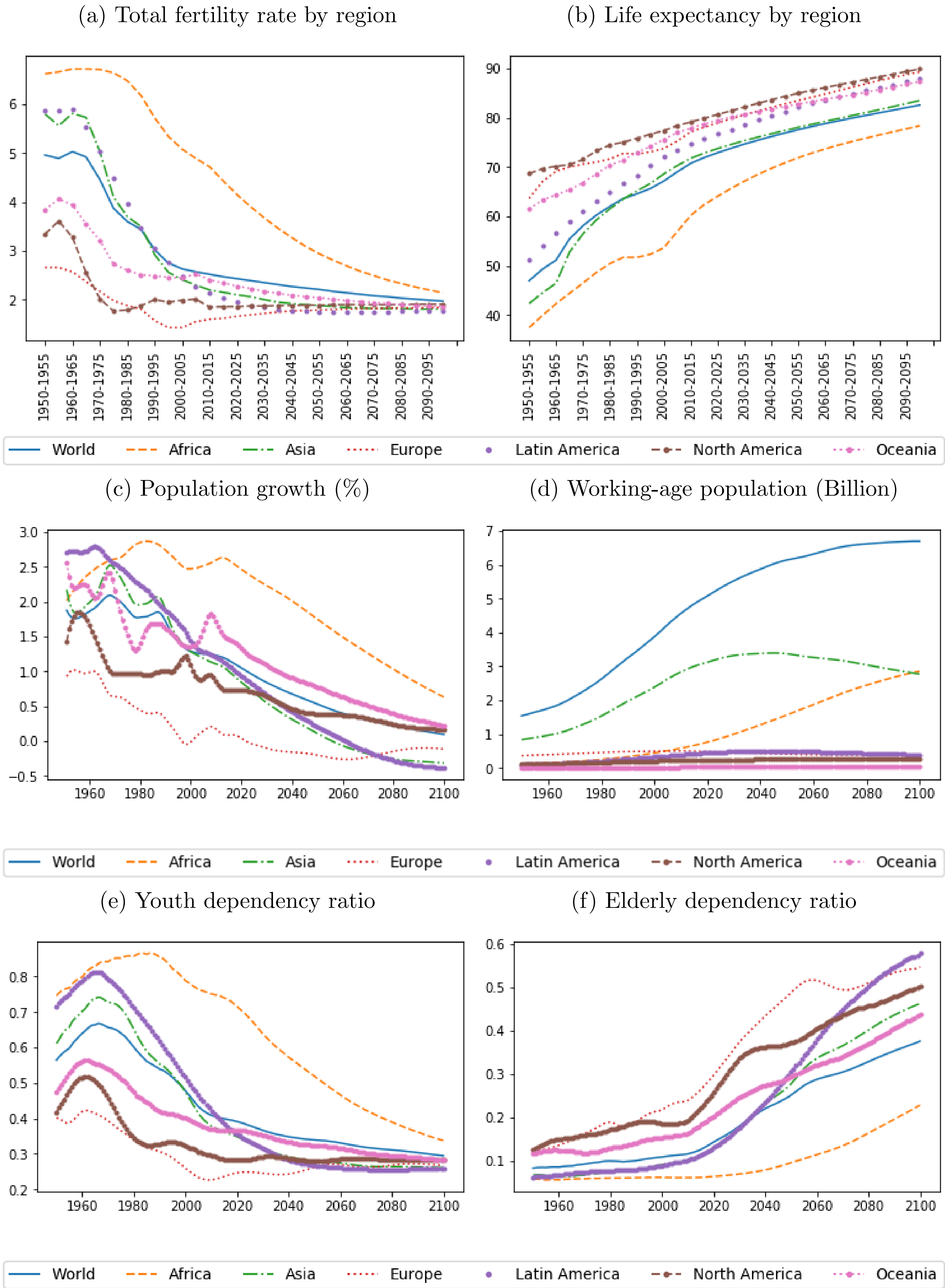
1 Introduction

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) (Figures 1a and 1b). The 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. Due to the fertility decline, population growth has slowed down all around the world (Figure 1c). 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, with the growth rate expected to further decline to around 0.5 percent by 2050. The combination of declining fertility and increasing longevity has substantially changed age structure, leading to an aging world. The youth dependency ratio (the ratio of population under 15 to population over 15-64) started to decline in the 1980s (Figure 1e), and the elderly dependency ratio (the ratio of population over 64 to population over 15-64) has been increasing and is expected to increase rapidly over 2020-2050 (Figure 1f). The population aged 60 or over is projected to rise from around 1 billion in 2020 to almost 2 billion by 2050, representing 22 percent of the world population.

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 (Figures 1a and 1b) (Bloom and Luca 2016). 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 (Figure 1c). In contrast, Africa has been showing strong growth since 1950, with the growth rate still as high as 2.5 percent nowadays. The size of working-age population, which is a key driver of shaping the landscape of the world economy, also displays dramatic regional differences (Figure 1d). 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 before declining. 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 since 2011. North America and Oceania have been experiencing low but steady increases in the working-age population because of migration into the two regions. In addition, the change in age structure also presents distinct asymmetry between countries and regions (Figures 1e and 1f). Population aging has started in advanced economies, followed by developing countries with a sizable delay.

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.

Figure 1: Global demographic change

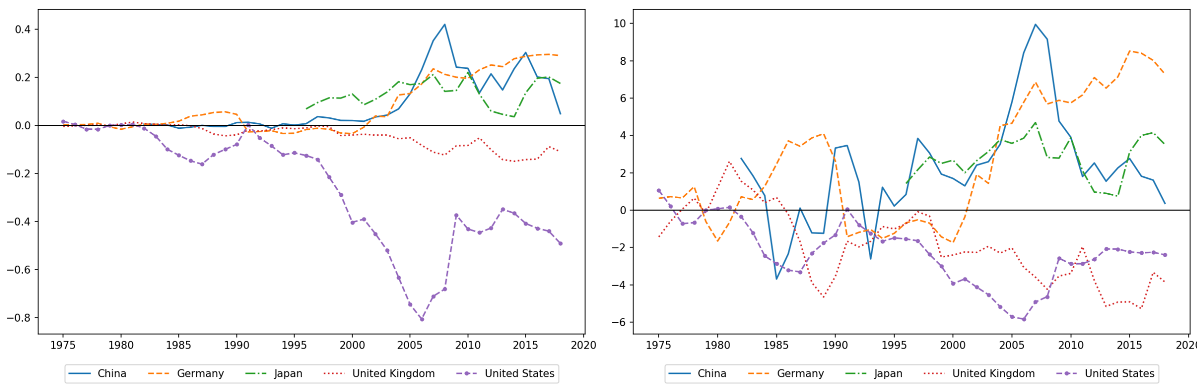


This global demographic change has been accompanied by another worldwide economic phenomenon that global current account imbalances (or global imbalances) have increased persistently around the world since the 1980s (Figure 2). One prominent pattern of the global imbalances is that capital has flowed 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).

Figure 2: Current account balances

(a) Current account (Trillion USD)

(b) Current account (% GDP)



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. 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.

This paper introduces demographic structure and pension systems into a four-stage overlapping-generation (OLG) model of a small open economy, and derives analytical solutions to national saving and the current account which depend on demographic and pension structure as well as other economic parameters. The model is closely related to several theoretical studies that introduce demographic structure and pension systems into 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 several main differences. First, while multiple-country models do not produce analytical solutions, our model considers a small open economy and ensures an analytical solution which links a large number of factors to the current account transparently. Second, our model 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. Third, our model introduces childhood as a life stage and links our analysis to the dependency hypothesis in the empirical literature on national saving, while the above studies mostly ignore the stage of childhood.

The remainder of this paper is organized as follows. Section 2 provides a four-period OLG model of a small open economy, and derives analytical solutions which link a large set of factors including demographic and pension structure to national saving and current accounts. Section 3 presents the impacts of demographic change alone, and Section 4 focuses on the interaction between demographic change and pension structure, while Section 5 focuses on the interaction between demographic change and productivity growth. Section 6 applies the model to four major economies: the United States, Japan, China and India. Section 7 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 (PAYG) 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.

2.2 Demographics

Each individual lives up to four stages of life: child (C), young worker (Y), old worker (O), retiree (R), each representing 20 years. At the beginning of time period t, young workers give birth to children, and the new generation is homogeneous and does not hold assets. The size of each new generation grows at a gross rate of n_t as

$$N_t^C = n_t N_t^Y \tag{1}$$

where N_t^C and N_t^Y represent the size of children and young workers respectively. 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. A child in period t turns into a young worker without mortality at the beginning of period $t+1$, and further turns into a prime worker without mortality at the beginning of period $t+2$, and survives into retirement with a probability of p_{t+1} at the beginning of period $t+3$. It follows that the mortality rate in period $t+1$ is

$$m_{t+1} = 1 - p_{t+1} \tag{2}$$

The dynamics of cohort sizes are

$$N_{t+1}^O = N_t^Y, \quad N_{t+1}^R = p_{t+1} N_t^O \tag{3}$$

where N_t^O and N_t^R represent the size of old workers and retirees respectively.

Children do not work and depend on young workers for consumption. Young and old workers are endowed with different labor productivity. The productivity ratio of old to young workers is represented by $e \geq 1$.

2.3 Pension system

Assume there is a pension system. A retiree in period t receives pension benefits, $\rho_t e w_{t-1}$, depending on the past labor income $e w_{t-1}$ and the replacement rate ρ_t, where e is effective labor and w_{t-1} is the wage rate. The system is financed by taxing labor income of workers at rate τ_t. Assume the system runs a balanced budget each period.

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

Equivalently,

$$\rho_t = \tau_t \frac{n_{t-2}(n_{t-1}+e)}{p_t e} \frac{w_t}{w_{t-1}}, \quad \tau_t = \rho_t \frac{p_t e}{n_{t-2}(n_{t-1}+e)} \frac{w_{t-1}}{w_t} \tag{5}$$

If $\tau_t = \bar{\tau}$ is constant, the system is balanced with defined contributions; if $\rho_t = \bar{\rho}$ is constant, the system is balanced with defined benefit. If $\tau_t = \rho_t = 0$, the system becomes completely pre-funded, where all retirees finance their consumption by private saving when they are young.

2.4 Consumers

Each worker inelastically supplies one unit of labor in a competitive labor market, and retires when she is old. The wage of effective labor is denoted by w_t. A young individual 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. A perfect international asset market implies that the rate of return on capital must be equal to the world interest rate. 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

$$\begin{aligned} n_t c_t^C + c_t^Y + b_{t+1}^O + k_{t+1}^O &= (1-\tau_t)w_t & (6)\\ c_{t+1}^O + b_{t+2}^R + k_{t+2}^R &= (1+r)(b_{t+1}^O + k_{t+1}^O) + (1-\tau_{t+1})ew_{t+1} & (7)\\ c_{t+2}^R &= \frac{(1+r)(b_{t+2}^R + k_{t+2}^R)}{p_{t+2}} + \rho_{t+2}ew_{t+1} & (8)\end{aligned}$$

where the first equation is for the young-worker period, the second one is for the old-worker period, and the third one is for the retirement period. This implies the intertemporal budget constraint as

$$n_t c_t^C + c_t^Y + \frac{c_{t+1}^O}{1+r} + p_{t+2}\frac{c_{t+2}^R}{(1+r)^2} = \omega_t \tag{9}$$

where ω_t denotes lifetime wealth of a young individual in period t defined as

$$\omega_t = (1-\tau_t)w_t + \frac{(1-\tau_{t+1})ew_{t+1}}{1+r} + p_{t+2}\frac{\rho_{t+2}ew_{t+1}}{(1+r)^2} \tag{10}$$

Each young individual at time t makes a consumption plan $\{c_t^C, c_t^Y, c_{t+1}^O, c_{t+2}^R\}$, subject to the intertemporal budget constraint, to maximize her lifetime utility

$$E_t\{u_t\} = \lambda n_t \frac{(c_t^C)^{1-1/\sigma}}{1-1/\sigma} + \frac{(c_t^Y)^{1-1/\sigma}}{1-1/\sigma} + \beta\frac{(c_{t+1}^O)^{1-1/\sigma}}{1-1/\sigma} + \beta^2 p_{t+2}\frac{(c_{t+2}^R)^{1-1/\sigma}}{1-1/\sigma} \tag{11}$$

where $\sigma > 0$ denotes the elasticity of intertemporal substitution, $0 < \beta < 1$ denotes the subjective discount factor, and λ measures the degree to which parents care about their children. The optimal consumption for each individual can be solved as

$$\begin{aligned} c_t^C &= \frac{\lambda^\sigma \omega_t}{n_t\lambda^\sigma + 1 + \beta^\sigma(1+r)^{\sigma-1} + p_{t+2}\left[\beta^\sigma(1+r)^{(\sigma-1)}\right]^2} & (12)\\ c_t^Y &= \frac{\omega_t}{n_t\lambda^\sigma + 1 + \beta^\sigma(1+r)^{\sigma-1} + p_{t+2}\left[\beta^\sigma(1+r)^{(\sigma-1)}\right]^2} & (13)\\ c_{t+1}^O &= \frac{\beta^\sigma(1+r)^\sigma\omega_t}{n_t\lambda^\sigma + 1 + \beta^\sigma(1+r)^{\sigma-1} + p_{t+2}\left[\beta^\sigma(1+r)^{(\sigma-1)}\right]^2} & (14)\\ c_{t+2}^R &= \frac{\left[\beta^\sigma(1+r)^\sigma\right]^2\omega_t}{n_t\lambda^\sigma + 1 + \beta^\sigma(1+r)^{\sigma-1} + p_{t+2}\left[\beta^\sigma(1+r)^{(\sigma-1)}\right]^2} & (15)\end{aligned}$$

The saving of each individual at different life stages is

$$\begin{aligned} s_t^Y &= (1-\tau_t)w_t - (1+n_t\lambda^\sigma) * & (16)\\ &\quad \frac{\omega_t}{n_t\lambda^\sigma + 1 + (1+r)^{\sigma-1}\beta^\sigma + p_{t+2}\left[(1+r)^{(\sigma-1)}\beta^\sigma\right]^2} \\ s_{t+1}^O &= r(1-\tau_t)w_t + (1-\tau_{t+1})ew_{t+1} - \left[r(1+n_t\lambda^\sigma) + \beta^\sigma(1+r)^\sigma\right] * & (17)\\ &\quad \frac{\omega_t}{n_t\lambda^\sigma + 1 + \beta^\sigma(1+r)^{\sigma-1} + p_{t+2}\left[\beta^\sigma(1+r)^{(\sigma-1)}\right]^2} \\ s_{t+2}^R &= -\frac{1}{p_{t+2}}\left((1+r)(1-\tau_t)w_t + (1-\tau_{t+1})ew_{t+1}\right) + \frac{1}{p_{t+2}}\left((1+r)(1+n_t\lambda^\sigma) + \beta^\sigma(1+r)^\sigma\right) * \\ &\quad \frac{\omega_t}{n_t\lambda^\sigma + 1 + \beta^\sigma(1+r)^{\sigma-1} + p_{t+2}\left[\beta^\sigma(1+r)^{(\sigma-1)}\right]^2}\end{aligned}$$

The saving of a young worker is the difference between her after-tax labor income and young-period consumption. The saving of an old worker is the difference between her after-tax labor income, financial income (interest payment), and old-period consumption. The saving of a retiree is opposite to the sum of a young worker's saving and an old worker's saving, adjusted by the mortality rate, as below.

$$s_t^Y + s_{t+1}^O + p_{t+2}s_{t+2}^R = 0 \tag{18}$$

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

$$Y_t = A_t(K_t)^\alpha(L_t)^{1-\alpha} \tag{19}$$

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

$$A_{t+1} = g_{t+1}^{1-\alpha}A_t \tag{20}$$

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.

$$K_{t+1} = K_t + I_t \tag{21}$$

The firm maximizes the present value of entire profits as

$$\Pi = \sum_{t=0}^{\infty}\left(\prod_{s=0}^{t}\frac{1}{1+r}\right)(Y_t - w_tL_t - I_t) \tag{22}$$

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

$$r = \alpha A_t(k_t)^{\alpha-1} \tag{23}$$
$$w_t = (1-\alpha)A_t(k_t)^\alpha \tag{24}$$

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.

$$C_t = N_t^Cc_t^C + N_t^Yc_t^Y + N_t^Oc_t^O + N_t^Rc_t^R \tag{25}$$
$$S_t = N_t^Ys_t^Y + N_t^Os_t^O + N_t^Rs_t^R \tag{26}$$
$$K_{t+1} = N_t^Yk_{t+1}^O + N_t^Ok_{t+1}^R \tag{27}$$
$$B_{t+1} = N_t^Yb_{t+1}^O + N_t^Ob_{t+1}^R \tag{28}$$

(b) Capital accumulates through investment:

$$K_{t+1} = K_t + I_t \tag{29}$$

(c) The labor market clears:

$$L_t = N_t^Y + eN_t^O \tag{30}$$

(d) The goods market clears:

$$Y_t = C_t + I_t + T_t \tag{31}$$

where T_t represents trade balance in period t.

(e) The domestic capital market clears:

$$S_t = K_{t+1} - K_t + B_{t+1} - B_t = I_t + CA_t \tag{32}$$

where CA_t represents the current account in period t.

(f) The international asset market clears such that the rate of return on domestic capital must be equal to the world interest rate.

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.

$$k_t = \left(\frac{\alpha A_t}{r}\right)^{\frac{1}{1-\alpha}} \tag{33}$$

$$w_t = (1-\alpha)A_t\left(\frac{\alpha A_t}{r}\right)^{\frac{\alpha}{1-\alpha}} \tag{34}$$

Therefore,

$$\frac{w_{t+1}}{w_t} = g_{t+1}, \quad \frac{k_{t+1}}{k_t} = g_{t+1}, \quad \frac{K_{t+1}}{K_t} = g_{t+1}n_{t-1}\frac{n_t+e}{n_{t-1}+e}, \quad \frac{Y_{t+1}}{Y_t} = g_{t+1}n_{t-1}\frac{n_t+e}{n_{t-1}+e} \tag{35}$$

2.7 National saving, investment and current account

Given the equilibrium, we can derive national saving, investment and the current account in terms of output. The derivative of saving in terms of output for each generation, represented by S_t^Y, S_t^O, S_t^R in terms of Y_t respectively, as well as investment in terms of output, is presented in Appendix A. The current account in terms of output is

$$
\begin{aligned}
&\frac{CA_t}{Y_t} = \frac{S_t^Y + S_t^O + S_t^R - I_t}{Y_t} \\
&= \frac{n_{t-1}(1-\alpha)}{n_{t-1}+e}\Bigg\{1 - \frac{\rho_t p_t e}{g_t n_{t-2}(n_{t-1}+e)} \\
&\quad - (1+n_t\lambda^\sigma)\frac{\left(1-\frac{\rho_t p_t e}{g_t n_{t-2}(n_{t-1}+e)}\right) + \left(1-\frac{\rho_{t+1}p_{t+1}e}{g_{t+1}n_{t-1}(n_t+e)}\right)\frac{eg_{t+1}}{1+r} + \frac{p_{t+2}\rho_{t+2}eg_{t+1}}{(1+r)^2}}{n_t\lambda^\sigma + 1 + (1+r)^{\sigma-1}\beta^\sigma + p_{t+2}\left[(1+r)^{(\sigma-1)}\beta^\sigma\right]^2}\Bigg\} \\
&+ \frac{1-\alpha}{n_{t-1}+e}\Bigg\{\frac{r}{g_t}\left(1-\frac{\rho_{t-1}p_{t-1}e}{g_{t-1}n_{t-3}(n_{t-2}+e)}\right) + e\left(1-\frac{\rho_t p_t e}{g_t n_{t-2}(n_{t-1}+e)}\right) \\
&\quad - \left(r(1+n_{t-1}\lambda^\sigma) + \beta^\sigma(1+r)^\sigma\right)\frac{\left(1-\frac{\rho_{t-1}p_{t-1}e}{g_{t-1}n_{t-3}(n_{t-2}+e)}\right)\frac{1}{g_t} + \left(1-\frac{\rho_t p_t e}{g_t n_{t-2}(n_{t-1}+e)}\right)\frac{e}{1+r} + \frac{p_{t+1}\rho_{t+1}e}{(1+r)^2}}{n_{t-1}\lambda^\sigma + 1 + (1+r)^{\sigma-1}\beta^\sigma + p_{t+1}\left[(1+r)^{(\sigma-1)}\beta^\sigma\right]^2}\Bigg\} \\
&+ \frac{1-\alpha}{n_{t-2}(n_{t-1}+e)}\Bigg\{-\frac{1+r}{g_t g_{t-1}}\left(1-\frac{\rho_{t-2}p_{t-2}e}{n_{t-4}(n_{t-3}+e)g_{t-2}}\right) - \frac{e}{g_t}\left(1-\frac{\rho_{t-1}p_{t-1}e}{n_{t-3}(n_{t-2}+e)g_{t-1}}\right) \\
&\quad + \left((1+r)(1+n_{t-2}\lambda^\sigma) + \beta^\sigma(1+r)^\sigma\right) * \\
&\quad \frac{\left(1-\frac{\rho_{t-2}p_{t-2}e}{n_{t-4}(n_{t-3}+e)g_{t-2}}\right)\frac{1}{g_t g_{t-1}} + \left(1-\frac{\rho_{t-1}p_{t-1}e}{n_{t-3}(n_{t-2}+e)g_{t-1}}\right)\frac{e}{(1+r)g_t} + \frac{p_t\rho_t e}{(1+r)^2 g_t}}{n_{t-2}\lambda^\sigma + 1 + (1+r)^{\sigma-1}\beta^\sigma + p_t\left[(1+r)^{(\sigma-1)}\beta^\sigma\right]^2}\Bigg\} \\
&- \frac{\alpha}{r}\left(g_{t+1}n_{t-1}\frac{n_t+e}{n_{t-1}+e} - 1\right)
\end{aligned}
\tag{36}
$$

The current account consists of four components: the saving of young workers, the saving of old workers, the saving of retirees, and investment. The above equation indicates that the current account depends on: (1) the past and current 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, (8) the subjective discount factor, (9) the life-cycle productivity growth rate, (10) the degree of parent caring about their children. For simplicity, we make several assumptions as follows.

Assumption 1 *The parameters satisfy the following conditions:*

(a) $(1+r)\beta = 1$ *such that consumers would choose a flat consumption path without a tilting motive when the mortality rate is zero;*

(b) $\lambda = 1$ *such that parents care about their children equally as themselves;*

(c) e *is large such that the saving of a young worker is negative, i.e., a young worker borrows;*

(d) ρ *is small such that the saving of a retiree is negative, i.e., a retiree dis-saves.*

Assume that population age structure is stationary before demographic shocks occur.

The current account and the net foreign asset position are initially in balance.

$$\begin{aligned}
\frac{CA_t}{Y_t} &= \frac{S_t^Y + S_t^O + S_t^R - I_t}{Y_t} \\
&= \frac{N_t^Y s_t^Y}{A_t k_t^\alpha \left(N_t^Y + eN_t^O\right)} + \frac{N_t^O s_t^O}{A_t k_t^\alpha \left(N_t^Y + eN_t^O\right)} + \frac{N_t^R s_t^R}{A_t k_t^\alpha \left(N_t^Y + eN_t^O\right)} \\
&= \frac{s_t^Y}{A_t k_t^\alpha (1+e)} + \frac{s_t^O}{A_t k_t^\alpha (1+e)} + \frac{p_t s_t^R}{A_t k_t^\alpha (1+e)} \\
&= 0
\end{aligned} \tag{37}$$

We now investigate the effects of demographic-related factors on national saving and international capital flows. The first one focuses on demographic change alone, and the second one on the interaction between demographic change and productivity growth, and the third one on the interaction between demographic change and pension structure. Assume that all shocks are anticipated.

3 Effects of demographic change

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

$$\begin{aligned}
&\frac{CA_t}{Y_t} = \frac{S_t^Y + S_t^O + S_t^R - I_t}{Y_t} \\
&= \frac{n_{t-1}(1-\alpha)}{n_{t-1}+e}\left\{1 - (1+n_t)\frac{1+\frac{e}{1+r}}{n_t + 1 + \frac{1}{1+r} + p_{t+2}\frac{1}{(1+r)^2}}\right\} \\
&+ \frac{1-\alpha}{n_{t-1}+e}\left\{r + e - (r(1+n_{t-1})+1)\,\frac{1+\frac{e}{1+r}}{n_{t-1} + 1 + \frac{1}{1+r} + p_{t+1}\frac{1}{(1+r)^2}}\right\} \\
&+ \frac{1-\alpha}{n_{t-2}(n_{t-1}+e)}\left\{-(1+r+e) + ((1+r)(1+n_{t-2})+1)\,\frac{1+\frac{e}{1+r}}{n_{t-2} + 1 + \frac{1}{1+r} + p_t\frac{1}{(1+r)^2}}\right\} \\
&- \frac{\alpha}{r}\left(n_{t-1}\frac{n_t+e}{n_{t-1}+e} - 1\right)
\end{aligned} \tag{38}$$

Proposition 1 *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, given Assumption 1,*

(a) S_t^Y/Y_t *decreases in* n_{t-1}*, and decreases in* n_t*, and decreases in* m_{t+2}*;*

(b) S_t^O/Y_t *decreases in* n_{t-1}*, and decreases in* m_{t+1}*;*

(c) S_t^R/Y_t *increases in* n_{t-2}*, and increases in* n_{t-1}*, and decreases in* m_t*;*

(d) I_t/Y_t *increases in* n_{t-1}*, and increases in* n_t*, and is independent of mortality rates;*

(e) CA_t/Y_t *increases in* n_{t-2}*, decreases in* n_{t-1}*, and decreases in* n_t*, and decreases in* m_t, m_{t+1} *and* m_{t+2}*.*

The proposition indicates that fertility change affects both saving and investment. S_t^Y/Y_t decreases in n_{t-1} because when n_{t-1} increases, the share of young workers in total labor force increases and thus the saving-output ratio increases. S_t^Y/Y_t decreases in n_t because child dependency increases. S_t^O/Y_t depends on n_{t-1} through several channels: (1) old workers need to pay their borrowing when they are young; (2) old workers consume less because of higher child dependency; (3) the share of old workers in total labor share in period t decreases and thus the saving-output ratio decreases. The overall effect is that S_t^O/Y_t decreases in n_{t-1}. S_t^R/Y_t decreases in n_{t-2} because retirees have less wealth accumulated before retirement, and increases in n_{t-1} because the young cohort size increases and thus the saving-ratio decreases. I_t/Y_t increases in n_{t-1} because the share of young workers in total labor force increases in n_{t-1} and thus the capital-output ratio increases. I_t/Y_t increases in n_t because more capital is needed to finance investment of future increased young labor.

In contrast with fertility change, mortality change only affects saving but not investment. S_t^Y/Y_t decreases in m_{t+2} because young workers consume less in the young period when they expect to live longer. The same logic applies to old workers and retirees. Investment is independent of mortality because retirees do not work at all.

The rest of this section considers the dynamics of saving and investment in response to different demographic shocks. Fertility and mortality shocks are separated, and both can be transitory, permanent and persistent. Suppose that the fertility rate remains at one and the mortality rate remains at $\bar{m}$ $(0 < \bar{m} < 1)$ before shocks occur.

3.1 Fertility change

Suppose that the mortality rate remains constant at $\bar{m}$ forever. We consider three scenarios of fertility shocks. Fertility change affects national saving and also investment, but the effect on investment dominates the effect on saving given empirically plausible parameter values.

3.1.1 Temporary fertility shock

Suppose that the fertility rate decreases in period $s + 1$, and then returns to one afterwards. Therefore, total population decreases in period $s+1$, and then flattens forever. Figure 3 presents the effects of this temporary fertility shock. In period $s + 1$, young workers borrow less because of lower child dependency, old workers and retirees do not change their saving, so national saving increases. As less children turns into young workers at the beginning of period $s+2$, investment decreases in period $s+1$, resulting in increasing current accounts. In period $s + 2$, young workers borrow less because the share of young workers out of labor force decreases, old workers save more because they pay less debt accumulated from the young period, retirees dis-save more because they accumulate more assets, so national saving increases further. As less young workers turn into old workers in period $s+2$, investment further decreases, and thus the current account further increases. In period $s + 3$, the saving of young and old workers returns to normal, but retirees dis-save even more, so national saving decreases. Meanwhile, investment returns to the baseline, leaving current account deficits. In period $s+4$, national saving and investment all return to the baseline, leaving current account in balance. However, the net foreign asset position increases above the baseline because population size decreases permanently and capital is too much for a smaller population.

Consider a cyclical temporary shock where the fertility rate decreases below one first, and then increases above one such that the size of the young generation remains at the baseline, and then returns to one afterwards. In such a case, total population decreases first, and then increases to the pre-shock level afterwards. The net foreign asset position increases first, and then decreases, and returns to the baseline eventually.

3.1.2 Permanent fertility shock

Suppose that the fertility rate deviates from one and remains at a constant level at n from period $s+1$ onward. Total population either expands ($n > 1$) or shrinks ($n < 1$) persistently. Figure 4 presents the effects of a permanent fertility shock with $n < 1$. The economy experiences a transition from period $s+1$ to $s+3$, and reaches a new steady state afterwards. During the transition, in period $s+1$, young workers borrow less because of lower child dependency, while old workers and retirees do not change their saving, resulting in increasing national saving. Investment decreases, and thus the current account increases. In period $s+2$, young workers borrow even less because the share of young workers out of labor force decreases, old workers save more because they pay less debt accumulated from the young period, and retirees dis-save more because they accumulate more assets before retirement, so national saving increases more. Investment decreases further, and thus the current account increases further. In period $s+3$, saving, investment and the current account all reach their new steady state. The net foreign asset position increases continuously.

3.1.3 Persistent fertility shock

Suppose that the fertility rate decreases continuously below one. Total population thus shrinks persistently at an increasing rate. Thus, investment decreases persistently and the current account also decreases persistently, resulting in increasing net foreign assets over time.

3.2 Mortality change

Mortality change only affects national saving but not investment. Suppose that the fertility rate remains at one forever. The current account in terms of output reduces to

$$\frac{CA_t}{Y_t} = \frac{1-\alpha}{1+e}\left\{ -\frac{2\left(1+\frac{e}{1+r}\right)}{2+\frac{1}{1+r}+\frac{p_{t+2}}{(1+r)^2}} - \frac{(2r+1)\left(1+\frac{e}{1+r}\right)}{2+\frac{1}{1+r}+\frac{p_{t+1}}{(1+r)^2}} + \frac{(2r+3)\left(1+\frac{e}{1+r}\right)}{2+\frac{1}{1+r}+\frac{p_t}{(1+r)^2}} \right\} \tag{39}$$

We consider two scenarios of mortality shocks: permanent and persistent mortality shock.

3.2.1 Temporary mortality shock

Suppose that the mortality rate decreases in period $s+2$ and then returns to the baseline. The sizes of children, young and old workers all remain stable, and the retired cohort increases in period $s+2$ and then returns to the baseline afterwards, and hence total population increases in period $s+2$ and returns to the baseline afterwards. Figure 5 presents the results of this mortality shock. As individuals anticipate the mortality change, young workers borrow less in period s, and old workers increase saving in period $s+1$ to accumulate more assets for higher retirement consumption. In contrast, retirees as a whole consume more as the number of retirees increases in period $s+2$. Therefore, national saving increases in period s, and then return to the baseline. Investment is not affected. The current account increases in period s, and increases further in period $s+1$, and then decreases in period $s+2$ before returning to the baseline. The net foreign asset position increases in period $s+1$, and further in period $s+2$, and then returns to the baseline since period $s+3$.

3.2.2 Permanent mortality shock

Suppose that the mortality rate decreases in period $s+2$ and then flattens forever. The sizes of children, young and old workers all remain stable, and the retired cohort increases permanently, and hence total population increases permanently. Figure 6 presents the results of this mortality shock. As individuals anticipate the mortality change, young workers borrow less since period s, and old workers start to increase saving in period $s+1$ to accumulate more assets for higher retirement consumption. In contrast, retirees as a whole consume more as the number of retirees increases since period $s+2$. Therefore, national saving increases in period s, and increases further in period $s+1$, and then return to the baseline. Investment is not affected. The current account increases in period s, and increases further in period $s+1$, and then returns to the baseline. The net foreign asset position increases in period $s+1$, and further in period $s+2$, and flattens forever.

3.2.3 Persistent mortality shock

Suppose that the mortality rate decreases from period $s+2$ 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 sizes of young and old workers remain stable, the retiree generation increases persistently, and hence total population increases persistently. Figure 7 presents the results of this mortality shock. Young workers continue to borrow less, and old workers continue to increase saving, while retirees as a whole increase consumption continuously. National saving increases in period s, and increases further in period $s+1$. Since period $s+2$, national saving does not remain stable but slightly decreases over time because we assume the mortality rate decreases linearly but national saving is not linear in mortality rates. The current account follows the changes of national saving as investment remains unchanged, and the net foreign asset position continues to improve.

The above analysis of fertility and mortality changes indicates that the impacts of demographic shocks depend on whether shocks are driven by fertility or mortality change, and also on whether shocks are temporary, permanent or persistent. Temporary shocks have temporary impacts on the current account, but can have temporary or persistent impacts on the net foreign asset position, depending on whether the shock changes population size in the long run. If population size does not change permanently, the impact of a temporary fertility shock on the net foreign assets would be completely reversed eventually. If population size changes permanently, the impact would be only partly reversed, leaving constant foreign assets, and the annuity value of foreign assets is consumed in the steady state. The impact of a temporary mortality shock on the net foreign asset position is completely reversed. Permanent shocks have temporary or permanent impacts on the current account, but the current account must be in balance in the long run. Permanent fertility shocks generate permanent current account changes while permanent mortality shocks generate temporary current account changes. In terms of net foreign assets, permanent fertility shocks have persistent impacts while permanent mortality shocks have permanent impacts. In persistent shocks, the current account is not in balance even in the long run and the net foreign asset position changes persistently.

In contrast with other macroeconomic shocks such as fiscal and monetary shocks, demographic shocks take a much longer time period. 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.

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 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 position 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**	**Current account**	**Foreign asset**
Fertility	Temporary	Temporary	Temporary	Temporary
	Temporary	Permanent	Temporary	Permanent
	Permanent	Persistent	Permanent	Persistent
	Persistent	Persistent	Persistent	Persistent
Mortality	Temporary	Temporary	Temporary	Temporary
	Permanent	Permanent	Temporary	Permanent
	Persistent	Persistent	Permanent	Persistent

4 Effects of demographic change and pension policy

Suppose that TFP remains constant, i.e., $g_t = 1$, and we introduce a PAYG pension system. The current account in terms of output reduces to

$$\begin{aligned}
\frac{CA_t}{Y_t} &= \frac{S_t^Y + S_t^O + S_t^R - I_t}{Y_t} \qquad (40)\\
&= \frac{n_{t-1}(1-\alpha)}{n_{t-1}+e}\Bigg\{1 - \frac{\rho_t p_t e}{n_{t-2}(n_{t-1}+e)} \\
&\quad -(1+n_t)\frac{\left(1-\frac{\rho_t p_t e}{n_{t-2}(n_{t-1}+e)}\right) + \left(1-\frac{\rho_{t+1}p_{t+1}e}{n_{t-1}(n_t+e)}\right)\frac{e}{1+r} + \frac{p_{t+2}\rho_{t+2}e}{(1+r)^2}}{n_t + 1 + \frac{1}{1+r} + p_{t+2}\frac{1}{(1+r)^2}}\Bigg\} \\
&\quad + \frac{1-\alpha}{n_{t-1}+e}\Bigg\{r\left(1-\frac{\rho_{t-1}p_{t-1}e}{n_{t-3}(n_{t-2}+e)}\right) + e\left(1-\frac{\rho_t p_t e}{n_{t-2}(n_{t-1}+e)}\right) \\
&\quad - (r(1+n_{t-1})+1)\,\frac{\left(1-\frac{\rho_{t-1}p_{t-1}e}{n_{t-3}(n_{t-2}+e)}\right) + \left(1-\frac{\rho_t p_t e}{n_{t-2}(n_{t-1}+e)}\right)\frac{e}{1+r} + \frac{p_{t+1}\rho_{t+1}e}{(1+r)^2}}{n_{t-1}+1+\frac{1}{1+r} + p_{t+1}\frac{1}{(1+r)^2}}\Bigg\} \\
&\quad + \frac{1-\alpha}{n_{t-2}(n_{t-1}+e)}\Bigg\{-(1+r)\left(1-\frac{\rho_{t-2}p_{t-2}e}{n_{t-4}(n_{t-3}+e)}\right) - e\left(1-\frac{\rho_{t-1}p_{t-1}e}{n_{t-3}(n_{t-2}+e)}\right) \\
&\quad + ((1+r)(1+n_{t-2})+1)\,\frac{\left(1-\frac{\rho_{t-2}p_{t-2}e}{n_{t-4}(n_{t-3}+e)}\right) + \left(1-\frac{\rho_{t-1}p_{t-1}e}{n_{t-3}(n_{t-2}+e)}\right)\frac{e}{1+r} + \frac{p_t\rho_t e}{(1+r)^2}}{n_{t-2}+1+\frac{1}{1+r}+p_t\frac{1}{(1+r)^2}}\Bigg\} \\
&\quad - \frac{\alpha}{r}\left(n_{t-1}\frac{n_t+e}{n_{t-1}+e} - 1\right)
\end{aligned}$$

Pension systems do not affect investment in terms of output in our model because they do not affect labor supply given households are assumed to supply labor inelastically and retire at a fixed age. But pension systems can affect national saving. 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 through pension transfers. 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.

4.1 Pension reform without demographic change

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

$$\begin{aligned}\frac{CA_t}{Y_t} = \frac{1-\alpha}{1+e}\Bigg\{ & 1 - \frac{\rho_t \bar{p} e}{1+e} - 2\frac{\left(1-\frac{\rho_t\bar{p}e}{1+e}\right)+\left(1-\frac{\rho_{t+1}\bar{p}e}{1+e}\right)\frac{e}{1+r}+\frac{\bar{p}\rho_{t+2}e}{(1+r)^2}}{2+\frac{1}{1+r}+\bar{p}\frac{1}{(1+r)^2}} \\ & + r\left(1-\frac{\rho_{t-1}\bar{p}e}{1+e}\right) + \left(1-\frac{\rho_t\bar{p}e}{1+e}\right)e - (2r+1)\frac{\left(1-\frac{\rho_{t-1}\bar{p}e}{1+e}\right)+\left(1-\frac{\rho_t\bar{p}e}{1+e}\right)\frac{e}{1+r}+\frac{\bar{p}\rho_{t+1}e}{(1+r)^2}}{2+\frac{1}{1+r}+\bar{p}\frac{1}{(1+r)^2}} \\ & - (1+r)\left(1-\frac{\rho_{t-2}\bar{p}e}{1+e}\right) - e\left(1-\frac{\rho_{t-1}\bar{p}e}{1+e}\right) + (2r+3)\frac{\left(1-\frac{\rho_{t-2}\bar{p}e}{1+e}\right)+\left(1-\frac{\rho_{t-1}\bar{p}e}{1+e}\right)\frac{e}{1+r}+\frac{\bar{p}\rho_t e}{(1+r)^2}}{2+\frac{1}{1+r}+\bar{p}\frac{1}{(1+r)^2}}\Bigg\}\end{aligned} \tag{41}$$

Proposition 2 *In a small open economy with perfect markets for goods, factors and assets, and without cross-border labor mobility, given Assumption 1,*

(a) S^Y_t/Y_t *decreases in* ρ_{t+2}*, and increases in* ρ_{t+1}*, and decreases in* ρ_t*;*

(b) S^O_t/Y_t *decreases in* ρ_{t+1}*, and decreases in* ρ_t*, and increases in* ρ_{t-1}*;*

(c) S^R_t/Y_t *decreases in* ρ_t*, and decreases in* ρ_{t-1}*, and increases in* ρ_{t-2}*;*

(d) S_t/Y_t *decreases in* ρ_{t+2}*, and increase or decrease in* ρ_{t+1}*, and decreases in* ρ_t*, and increases in* ρ_{t-1}*, and increases in* ρ_{t-2}*;*

(e) I_t/Y_t *is independent of replacement rates;*

(f) CA_t/Y_t *decreases in* ρ_{t+2}*, and increase or decrease in* ρ_{t+1}*, and decreases in* ρ_t*, and increases in* ρ_{t-1}*, and increases in* ρ_{t-2}*.*

Consider a pension reform of reducing pension benefits. This case is relevant for many developed countries which are aging fast with increasing pressure in pension sustainability. Suppose that the pension replacement rate remains at a positive level until period $s+1$, and decreases in period $s+2$ and flattens afterwards. Figure 8 presents the effects of this pension reform. In period s, young workers borrow less because they anticipate the pension reduction when they become old, so national saving increases and the current account increases. In period $s+1$, young workers slightly borrow more because they anticipate the tax reduction when they become old and the pension reduction when they become retired, and old workers increase their saving because they anticipate the pension reduction when they become retired, so national saving increases above the baseline. In period $s+2$, young workers borrow less and old workers save more because the pension system becomes more private-funded and workers have to finance their retirement with more private saving. On the other hand, retirees dis-save more because they receive less pension benefits. National saving increases above the baseline but by less than in period $s+1$. In period $s+3$, old workers decrease saving and retirees dis-save more, so national saving decreases from period $s+2$. In period $s+4$, retirees further dis-save more, and national saving and hence the current account return to balance. The net foreign asset position continues to increase since period $s+1$ until reaching a steady state in period $s+4$.

In an opposite case with pension benefit expansion, the effects on national saving and capital flows are opposite. This case is related to many developing countries which have low coverage or replacement rates in their PAYG pension systems or do not have formal PAYG systems, but gradually establish such pension systems or increase benefit rates of existing systems.

4.2 Temporary fertility shock

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

$$
\begin{aligned}
\frac{CA_t}{Y_t} &= \frac{S_t^Y + S_t^O + S_t^R - I_t}{Y_t} \\
&= \frac{n_{t-1}(1-\alpha)}{n_{t-1}+e}\Bigg\{1 - \frac{\rho\bar{p}e}{n_{t-2}(n_{t-1}+e)} \\
&\quad - (1+n_t)\frac{\left(1-\frac{\rho\bar{p}e}{n_{t-2}(n_{t-1}+e)}\right) + \left(1-\frac{\rho\bar{p}e}{n_{t-1}(n_t+e)}\right)\frac{e}{1+r} + \frac{\bar{p}\rho e}{(1+r)^2}}{n_t + 1 + \frac{1}{1+r} + \bar{p}\frac{1}{(1+r)^2}}\Bigg\} \\
&+ \frac{1-\alpha}{n_{t-1}+e}\Bigg\{r\left(1 - \frac{\rho\bar{p}e}{n_{t-3}(n_{t-2}+e)}\right) + e\left(1 - \frac{\rho\bar{p}e}{n_{t-2}(n_{t-1}+e)}\right) \\
&\quad - (r(1+n_{t-1})+1)\frac{\left(1-\frac{\rho\bar{p}e}{n_{t-3}(n_{t-2}+e)}\right) + \left(1-\frac{\rho\bar{p}e}{n_{t-2}(n_{t-1}+e)}\right)\frac{e}{1+r} + \frac{\bar{p}\rho e}{(1+r)^2}}{n_{t-1} + 1 + \frac{1}{1+r} + \bar{p}\frac{1}{(1+r)^2}}\Bigg\} \\
&+ \frac{1-\alpha}{n_{t-2}(n_{t-1}+e)}\Bigg\{-(1+r)\left(1 - \frac{\rho\bar{p}e}{n_{t-4}(n_{t-3}+e)}\right) - e\left(1 - \frac{\rho\bar{p}e}{n_{t-3}(n_{t-2}+e)}\right) \\
&\quad + ((1+r)(1+n_{t-2})+1)\frac{\left(1-\frac{\rho\bar{p}e}{n_{t-4}(n_{t-3}+e)}\right) + \left(1-\frac{\rho\bar{p}e}{n_{t-3}(n_{t-2}+e)}\right)\frac{e}{1+r} + \frac{\bar{p}\rho e}{(1+r)^2}}{n_{t-2} + 1 + \frac{1}{1+r} + \bar{p}\frac{1}{(1+r)^2}}\Bigg\} \\
&- \frac{\alpha}{r}\left(n_{t-1}\frac{n_t+e}{n_{t-1}+e} - 1\right)
\end{aligned}
$$

Suppose that the fertility rate decreases in period $s+1$ and then returns to one afterwards. Figure 9 presents the effects of this temporary fertility shock in the cases of defined contributions and benefits respectively. In the case of defined contributions, the pension replacement rate decreases in period $s+2$ and decreases further in period $s+3$ before returning to the pre-shock level in period $s+4$. In anticipation of pension reductions, young workers in periods $s+1$ and $s+2$ borrow less before returning to the baseline in period $s+3$. Similarly, old workers in periods $s+1$ and $s+2$ also increase saving before returning to the baseline in period $s+3$. Since young and old workers save more in periods $s+1$ and $s+2$, retirees dis-save more in periods $s+2$ and $s+3$. National saving increases in periods $s+1$ and $s+2$, but decreases in period $s+3$ before returning to the baseline in period $s+4$. Investment decreases in period $s+1$ and decreases further in period $s+2$, and then returns to the baseline. Therefore, the current account increases in period $s+1$ and further increases in period $s+2$, and decreases below the baseline in period $s+3$ before returning to the baseline. The net foreign asset position increases in period $s+2$ and $s+3$, and slightly decrease in period $s+4$, and then flattens afterwards. In the case of defined benefits, the pension tax rate increases temporarily in periods $s+2$

and $s+3$, and the effects on saving for each generation are different while the effects on investment are the same. Similar to the first case, young workers borrow less in periods $s+1$ and $s+2$, and slightly borrow more in period $s+3$ before returning to the baseline. In contrast with the first case, old workers decrease their saving in periods $s+2$ and $s+3$ because they are faced with higher pension taxes, and increase saving in period $s+4$ before returning to the baseline afterwards. Retirees dis-save slightly more since period $s+2$ until returning to the baseline.

4.3 Permanent fertility shock

Consider $g_t = 1, p_t = \bar{p}, \rho_t = \rho$. Suppose that the fertility rate decreases in period $s+1$ permanently, and thus total population shrinks persistently. Figure 10 presents the effects of this permanent fertility shock in the cases of defined contributions and benefits respectively. The economy experiences a similar transition process that occurs in the above temporary fertility shock, and then reaches a new steady state with the current account and the net foreign asset position increasing persistently. The difference between the two cases of pension arrangements is quantitatively small in the steady state.

4.4 Permanent mortality shock

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

$$
\begin{aligned}
\frac{CA_t}{Y_t} &= \frac{S_t^Y + S_t^O + S_t^R - I_t}{Y_t} \\
&= \frac{1-\alpha}{1+e}\Bigg\{1 - \frac{\rho p_t e}{1+e} - 2\frac{\left(1-\frac{\rho p_t e}{1+e}\right) + \left(1-\frac{\rho p_{t+1} e}{1+e}\right)\frac{e}{1+r} + \frac{p_{t+2}\rho e}{(1+r)^2}}{2 + \frac{1}{1+r} + p_{t+2}\frac{1}{(1+r)^2}} \\
&+ r\left(1 - \frac{\rho p_{t-1} e}{1+e}\right) + e\left(1 - \frac{\rho p_t e}{1+e}\right) - (2r+1)\frac{\left(1-\frac{\rho p_{t-1} e}{1+e}\right) + \left(1-\frac{\rho p_t e}{1+e}\right)\frac{e}{1+r} + \frac{p_{t+1}\rho e}{(1+r)^2}}{2 + \frac{1}{1+r} + p_{t+1}\frac{1}{(1+r)^2}} \\
&- (1+r)\left(1 - \frac{\rho p_{t-2} e}{1+e}\right) - e\left(1 - \frac{\rho p_{t-1} e}{1+e}\right) + (2r+3)\frac{\left(1-\frac{\rho p_{t-2} e}{1+e}\right) + \left(1-\frac{\rho p_{t-1} e}{1+e}\right)\frac{e}{1+r} + \frac{p_t\rho e}{(1+r)^2}}{2 + \frac{1}{1+r} + p_t\frac{1}{(1+r)^2}}\Bigg\}
\end{aligned}
$$

Suppose that p_{s+2} increases and flattens forever. Figure 11 presents the effects of this permanent fertility shock in the cases of defined contributions and benefits respectively. In the case of defined contributions, the pension replacement rate decreases since period $s+2$ because total pension contributions remain unchanged but more workers survive into retirement. Young workers borrow less since period s because they anticipate the reduction of pension benefits when they become retirees. Similarly, old workers increase saving since period $s+1$. Therefore, retirees dis-save more since period $s+2$. National saving thus increases in periods s and $s+1$ before returning to the baseline. The current account follows the same pattern as investment is independent of mortality rates. In the case of defined benefits, the pension tax rate increases since period $s+2$. Young workers reduce borrowing in periods $s+1$ and $s+2$ because they anticipate the increase of pension taxes when they become old. They reduce borrowing in period $s+1$ by more than in period $s+2$ because the increase of pension contributions in period $s+1$ falls completely on young workers while the increase in period $s+2$ is shared by young and old workers. Their borrowing remains lower than the baseline after period $s+2$ because the increase of pension taxes has a smaller effect than the decrease of consumption. Old workers decrease saving because the increase of pension taxes has a larger effect than the decrease of consumption. Retirees dis-save more since period $s+2$. National saving increases in period $s+1$, and decreases in periods $s+2$ and $s+3$ before returning to the baseline afterwards.

5 Effects of demographic change and productivity growth

Suppose that TFP rises over time. A TFP shock is: (1) temporary if the productivity level changes temporarily but returns to the previous level afterwards, and (2) permanent if the productivity growth rate changes temporarily and thus the level changes permanently, and (3) persistent if the growth rate changes permanently and thus the level changes continuously. This section considers persistent productivity shocks together with demographic shocks.

5.1 Productivity growth without pensions

If $\rho_t = 0$, the current account in terms of output reduces to

$$
\begin{aligned}
\frac{CA_t}{Y_t} &= \frac{S_t^Y + S_t^O + S_t^R - I_t}{Y_t} \\
&= \frac{n_{t-1}(1-\alpha)}{n_{t-1}+e}\left\{1-(1+n_t)\frac{1+\frac{eg_{t+1}}{1+r}}{n_t+1+\frac{1}{1+r}+p_{t+2}\frac{1}{(1+r)^2}}\right\} \\
&+ \frac{1-\alpha}{n_{t-1}+e}\left\{\frac{r}{g_t}+e-(r(1+n_{t-1})+1)\frac{\frac{1}{g_t}+\frac{e}{1+r}}{n_{t-1}+1+\frac{1}{1+r}+p_{t+1}\frac{1}{(1+r)^2}}\right\} \\
&+ \frac{1-\alpha}{n_{t-2}(n_{t-1}+e)}\left\{-\frac{1+r}{g_t g_{t-1}}-\frac{e}{g_t}+((1+r)(1+n_{t-2})+1)\frac{\frac{1}{g_t g_{t-1}}+\frac{e}{(1+r)g_t}}{n_{t-2}+1+\frac{1}{1+r}+p_t\frac{1}{(1+r)^2}}\right\} \\
&- \frac{\alpha}{r}\left(g_{t+1}n_{t-1}\frac{n_t+e}{n_{t-1}+e}-1\right)
\end{aligned}
$$

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, given Assumption 1,*

(a) S_t^Y/Y_t decreases in g_{t+1};

(b) S_t^O/Y_t decreases in g_t;

(c) S_t^R/Y_t increases in g_{t-1} and g_t;

(d) S_t/Y_t increases in g_{t-1}, and increases or decreases g_t, and decreases in g_{t+1};

(e) I_t/Y_t increases in g_{t+1};

(f) CA_t/Y_t increases in g_{t-1}, and increases or decreases g_t, and increases in g_{t+1}.

Productivity growth can affect both national saving and investment. The interactive term $g_{t+1}(n_t+e)$ indicates that the current account in terms of output depends on labor growth and productivity growth separately and also interactively. If $n_t = 1$, the above equation further reduces to

$$\frac{CA_t}{Y_t} = \frac{1-\alpha}{1+e}\left\{1 - 2\frac{1+\frac{eg_{t+1}}{1+r}}{2+\frac{1}{1+r}+\bar{p}\frac{1}{(1+r)^2}} + \frac{r}{g_t} + e - (2r+1)\frac{\frac{1}{g_t}+\frac{e}{1+r}}{2+\frac{1}{1+r}+\bar{p}\frac{1}{(1+r)^2}} \right.$$
$$\left. - \frac{1+r}{g_t g_{t-1}} - \frac{e}{g_t} + (2r+3)\frac{\frac{1}{g_t g_{t-1}}+\frac{e}{(1+r)g_t}}{2+\frac{1}{1+r}+\bar{p}\frac{1}{(1+r)^2}}\right\} - \frac{\alpha}{r}(g_{t+1}-1)$$

This captures the effect of productivity growth when demographic structure is stable. If productivity growth remains at one until period $s+1$, and increases permanently in period $s+2$. Figure 12 presents the effects of this persistent productivity shock. Young workers borrow more for higher consumption since period $s+1$ because they are faced with higher lifetime wealth due to productivity growth. Old workers increase saving after period $s+2$ because the increase of productivity growth has a larger effect than the increase of consumption. Retirees dis-save more since period $s+2$. National saving decreases in period $s+1$, and decreases less in period $s+2$ before returning to a new steady state. Investment increases permanently since period $s+1$ due to the productivity growth. National saving and investment contribute to the current account in the same direction, and the impact of investment dominates the impact of national saving. The net foreign asset position continuously decreases since period $s+2$.

5.2 Fertility decrease and productivity growth without pensions

Consider the effect of permanent fertility decrease and persistent productivity growth in the absence of pension systems. Figure 13 presents the effects of this shock. In the shock of a permanent fertility decrease above, the current account does not return to balance in the long run. In contrast, an additional shock of persistent productivity growth can offset the effect of fertility declines on the current account.

5.3 Productivity growth with pensions

Consider the effect of productivity growth on pension systems when age structure is stationary. Suppose that the productivity growth rate increases permanently in period $s+2$. Figure 14 presents the effects of this shock in the cases of defined contributions and benefits respectively. In the case of defined contributions, pension benefits increase since period $s+2$. Young workers increase consumption and borrow more in period s and even more in period $s+1$. Old workers also increase consumption and decrease saving in period $s+1$, and decrease saving by less in period $s+2$. Therefore, retirees dis-save less. National saving decreases period s and experiences a transition process before reaching a new steady state since period $s+3$. Investment increases permanently since period $s+1$. National saving and investment contribute to the current account in the same direction, and the impact of investment dominates the impact of national saving. The net foreign asset position decreases continuously. In the case of defined benefits, the tax rate decreases since period $s+2$. Young workers borrow more while old workers increase saving. National saving decreases while investment increases, leading to current account deficits.

5.4 Fertility decrease and productivity growth with pensions

Consider persistent productivity growth and permanent fertility decline. Suppose that the fertility rate decreases to 0.9 permanently in period $s+1$ while the productivity growth rate increases to 1.1 permanently in period $s+2$. Figure 15 presents the effects of this shock in the cases of defined contributions and benefits respectively. One key insight of the results is that the persistent productivity shock can offset the persistent fertility shock in the effects on national saving and the current account.

6 Discussion (in progress)

The previous analysis assumes that all shocks are completely anticipated. The degree to which shocks are anticipated affects the transition dynamics of the economy although it does not matter in the very long run.

7 Quantitative results (in progress)

This section applies the model to a number of economies, and predicts the demographic impacts on international capital flows in the future. We examine the United States, Japan, Germany, China, India. While the assumption of a small open economy ensures tractable results, it does not stand very well for large economies such as the United States. However, even the US accounts for only 20-25% of global GDP in the 2010s. Since demographic change is a long-term low-frequency process, demographic shocks would not change the interest rate dramatically. Therefore, it is not unreasonable to apply the model to an individual open economy even the United States. Faruqee (2002) builds a small open economy model to examine the impacts of demographic change in the United States and Japan respectively.

7.1 Calibration

The demographic transitions are based on the United Nations World Population Prospects 2019. Assume that the US and Japan run PAYG systems with a replacement of 50% before demographic shocks occur, while China and India have no pension systems. The annual real interest rates over the period of 2000-2019 are collected from the World Development Indicator (the real lending interest rate), and then are used to calculate the compound real interest rate over the period which serves as the constant interest rate for each country.

Table 2: Parameter calibration

Parameters	US	Japan	China	India
r	0.79	0.49	0.55	1.79
α	0.65	0.65	0.5	0.35
e	2	2	2	2
σ	2	2	2	2
β	0.6	0.6	0.6	0.6
λ	1	1	1	1
ρ	0.5	0.5	0	0

7.2 Results

Figure 16 presents quantitative projections of the demographic impacts on external balances of the four economies over the period of 2020-2100. Since all economies are expected to experience lower fertility and mortality in the upcoming decades compared to the second half of last century, they will all experience current account surpluses driven by demographic transitions. However, the scale differs across countries because of different aging processes. The US and India have relatively young population, and thus have moderate impacts on the current account. Japan and China are more rapidly aging, and have strong impacts in the next several decades.

8 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.

There are several 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, low generosity of pension systems tend to increase national saving and drive capital outflows.

Appendix A: Solution derivation

A pension system can be linked to saving and investment in terms of either tax rates or replacement rates based on the following relationship:

$$\tau_t = \frac{\rho_t p_t e}{n_{t-2}(n_{t-1}+e)} \frac{w_{t-1}}{w_t} = \frac{\rho_t p_t e}{g_t n_{t-2}(n_{t-1}+e)} \tag{42}$$

The saving of the young generation in terms of output is

$$\begin{aligned}
\frac{S_t^Y}{Y_t} &= \frac{N_t^Y s_t^Y}{A_t k_t^\alpha \left(N_t^Y + eN_t^O\right)} = \frac{n_{t-1} s_t^Y}{A_t k_t^\alpha \left(n_{t-1}+e\right)} \\
&= \frac{n_{t-1}(1-\alpha)}{n_{t-1}+e}\Bigg\{1-\tau_t-(1+n_t\lambda^\sigma) * \\
&\quad \left.\frac{(1-\tau_t)+(1-\tau_{t+1})\frac{eg_{t+1}}{1+r}+\frac{p_{t+2}\rho_{t+2}eg_{t+1}}{(1+r)^2}}{n_t\lambda^\sigma+1+(1+r)^{\sigma-1}\beta^\sigma+p_{t+2}\left[(1+r)^{(\sigma-1)}\beta^\sigma\right]^2}\right\} \\
&= \frac{n_{t-1}(1-\alpha)}{n_{t-1}+e}\Bigg\{1-\frac{\rho_t p_t e}{g_t n_{t-2}(n_{t-1}+e)}-(1+n_t\lambda^\sigma) * \\
&\quad \left.\frac{\left(1-\frac{\rho_t p_t e}{g_t n_{t-2}(n_{t-1}+e)}\right)+\left(1-\frac{p_{t+1}\rho_{t+1}e}{g_{t+1}n_{t-1}(n_t+e)}\right)\frac{eg_{t+1}}{1+r}+\frac{p_{t+2}\rho_{t+2}eg_{t+1}}{(1+r)^2}}{n_t\lambda^\sigma+1+(1+r)^{\sigma-1}\beta^\sigma+p_{t+2}\left[(1+r)^{(\sigma-1)}\beta^\sigma\right]^2}\right\}
\end{aligned} \tag{43}$$

The saving of the old generation in terms of output is

$$\begin{aligned}
\frac{S_t^O}{Y_t} &= \frac{N_t^O s_t^O}{A_t k_t^\alpha \left(N_t^Y + eN_t^O\right)} = \frac{s_t^O}{A_t k_t^\alpha \left(n_{t-1}+e\right)} \\
&= \frac{1-\alpha}{n_{t-1}+e}\Bigg\{\frac{r}{g_t}(1-\tau_{t-1})+(1-\tau_t)e-\left(r(1+n_{t-1}\lambda^\sigma)+\beta^\sigma(1+r)^\sigma\right) * \\
&\quad \left.\frac{(1-\tau_{t-1})\frac{1}{g_t}+(1-\tau_t)\frac{e}{1+r}+\frac{p_{t+1}\rho_{t+1}e}{(1+r)^2}}{n_{t-1}\lambda^\sigma+1+(1+r)^{\sigma-1}\beta^\sigma+p_{t+1}\left[(1+r)^{(\sigma-1)}\beta^\sigma\right]^2}\right\} \\
&= \frac{1-\alpha}{n_{t-1}+e}\Bigg\{\frac{r}{g_t}\left(1-\frac{\rho_{t-1}p_{t-1}e}{g_{t-1}n_{t-3}(n_{t-2}+e)}\right)+\left(1-\frac{\rho_t p_t e}{g_t n_{t-2}(n_{t-1}+e)}\right)e \\
&\quad -\left(r(1+n_{t-1}\lambda^\sigma)+\beta^\sigma(1+r)^\sigma\right) * \\
&\quad \left.\frac{\left(1-\frac{\rho_{t-1}p_{t-1}e}{g_{t-1}n_{t-3}(n_{t-2}+e)}\right)\frac{1}{g_t}+\left(1-\frac{\rho_t p_t e}{g_t n_{t-2}(n_{t-1}+e)}\right)\frac{e}{1+r}+\frac{p_{t+1}\rho_{t+1}e}{(1+r)^2}}{n_{t-1}\lambda^\sigma+1+(1+r)^{\sigma-1}\beta^\sigma+p_{t+1}\left[(1+r)^{(\sigma-1)}\beta^\sigma\right]^2}\right\}
\end{aligned} \tag{44}$$

The saving of the retired generation in terms of output is

$$
\begin{aligned}
\frac{S_t^R}{Y_t} &= \frac{N_t^R s_t^R}{A_t k_t^\alpha \left(N_t^Y + eN_t^O\right)} = \frac{p_t s_t^R}{A_t k_t^\alpha n_{t-2}\left(n_{t-1}+e\right)} \\
&= \frac{1-\alpha}{n_{t-2}(n_{t-1}+e)}\Bigg\{ -\frac{(1+r)(1-\tau_{t-2})}{g_t g_{t-1}} - \frac{e(1-\tau_{t-1})}{g_t} + \\
&\quad ((1+r)(1+n_{t-2}\lambda^\sigma)+\beta^\sigma(1+r)^\sigma)\,\frac{(1-\tau_{t-2})\frac{1}{g_t g_{t-1}} + (1-\tau_{t-1})\frac{e}{(1+r)g_t} + \frac{p_t\rho_t e}{(1+r)^2 g_t}}{n_{t-2}\lambda^\sigma + 1 + (1+r)^{\sigma-1}\beta^\sigma + p_{t+2}\left[(1+r)^{(\sigma-1)}\beta^\sigma\right]^2}\Bigg\} \\
&= \frac{1-\alpha}{n_{t-2}(n_{t-1}+e)}\Bigg\{ -\frac{1+r}{g_t g_{t-1}}\left(1-\frac{\rho_{t-2}p_{t-2}e}{n_{t-4}(n_{t-3}+e)g_{t-2}}\right) - \frac{e}{g_t}\left(1-\frac{\rho_{t-1}p_{t-1}e}{n_{t-3}(n_{t-2}+e)g_{t-1}}\right) \\
&\quad + ((1+r)(1+n_{t-2}\lambda^\sigma)+\beta^\sigma(1+r)^\sigma) * \\
&\quad \frac{\left(1-\frac{\rho_{t-2}p_{t-2}e}{n_{t-4}(n_{t-3}+e)g_{t-2}}\right)\frac{1}{g_t g_{t-1}} + \left(1-\frac{\rho_{t-1}p_{t-1}e}{n_{t-3}(n_{t-2}+e)g_{t-1}}\right)\frac{e}{(1+r)g_t} + \frac{p_t\rho_t e}{(1+r)^2 g_t}}{n_{t-2}\lambda^\sigma + 1 + (1+r)^{\sigma-1}\beta^\sigma + p_t\left[(1+r)^{(\sigma-1)}\beta^\sigma\right]^2}\Bigg\}
\end{aligned} \tag{45}
$$

The investment in terms of output is

$$
\frac{I_t}{Y_t} = \frac{K_{t+1}-K_t}{Y_t} = \frac{\alpha}{r}\left(g_{t+1}n_{t-1}\frac{n_t+e}{n_{t-1}+e} - 1\right) \tag{46}
$$

Appendix B: Theoretical results

(1) Effects of demographic change

Figure 3: Temporary fertility increase with permanent population size increase (no pension)

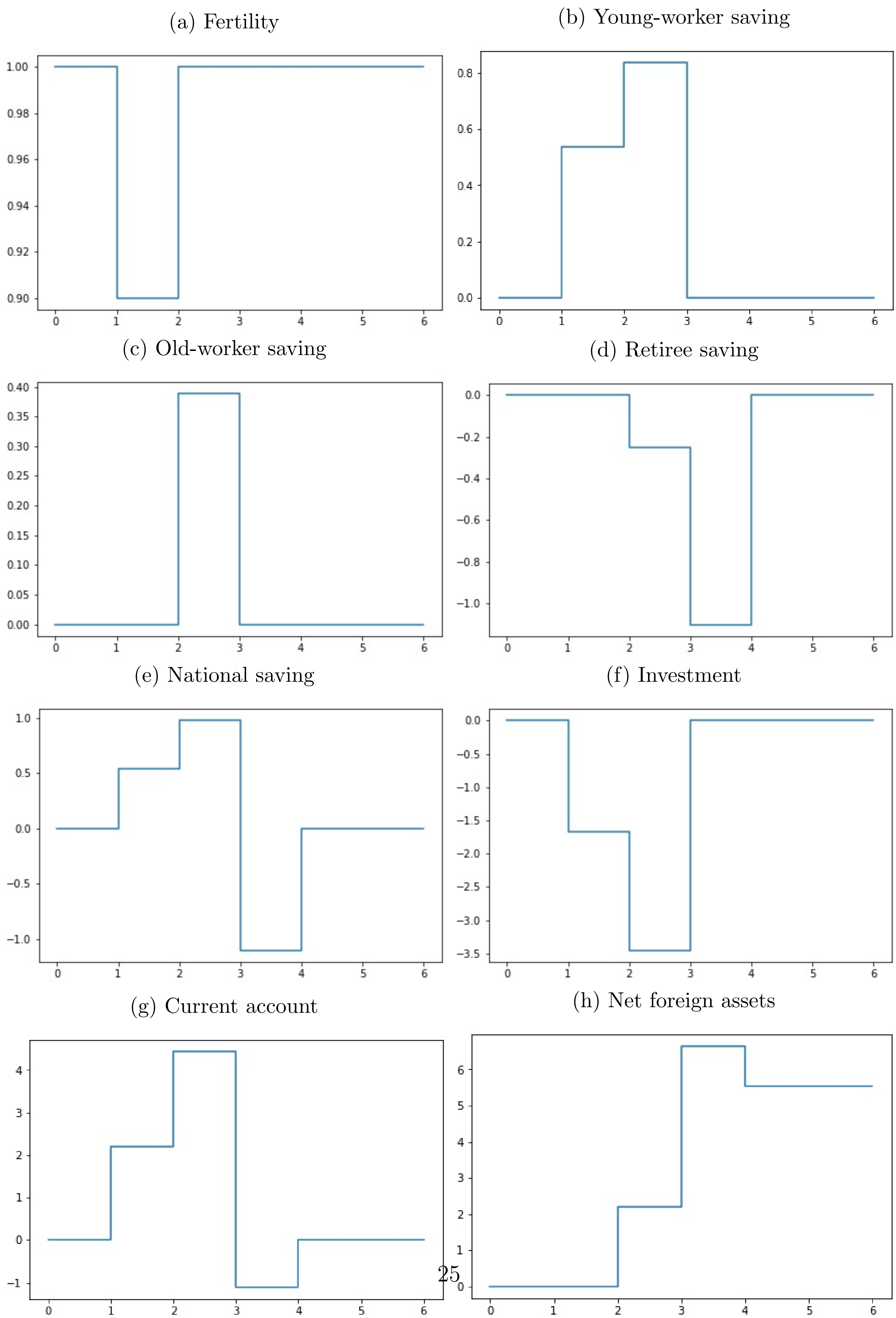
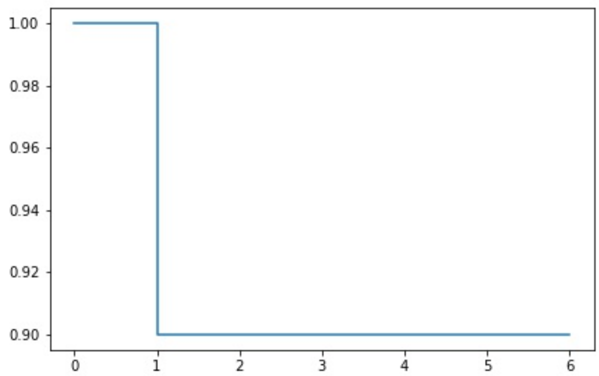
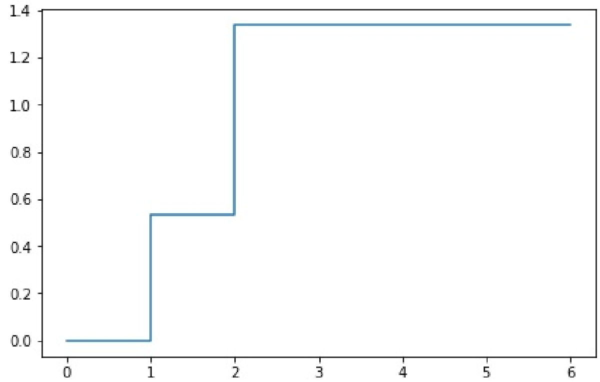


Figure 4: Permanent fertility increase with persistent population size increase (no pension)

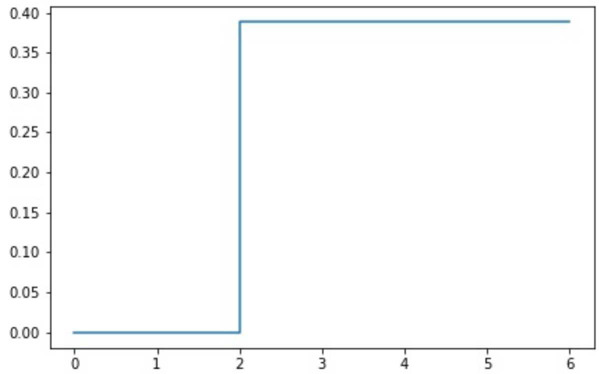
(a) Fertility



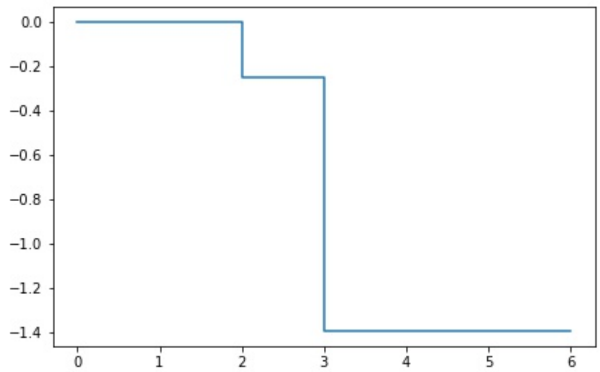
(b) Young-worker saving



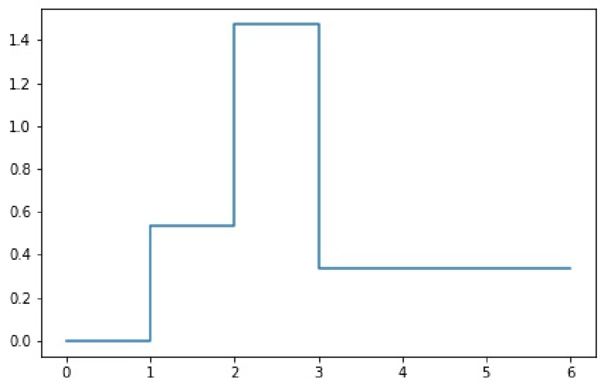
(c) Old-worker saving



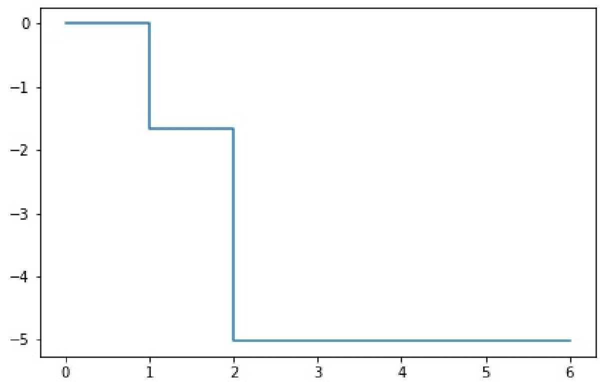
(d) Retiree saving



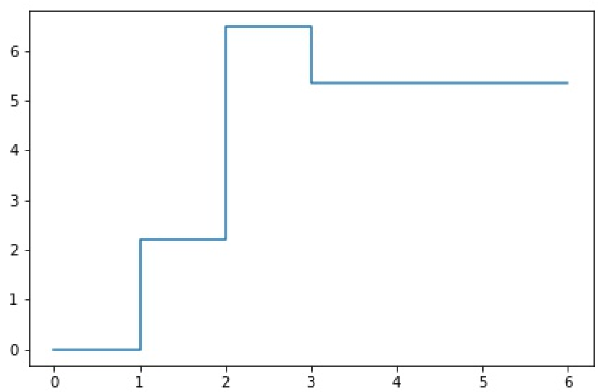
(e) National saving



(f) Investment



(g) Current account



(h) Net foreign assets

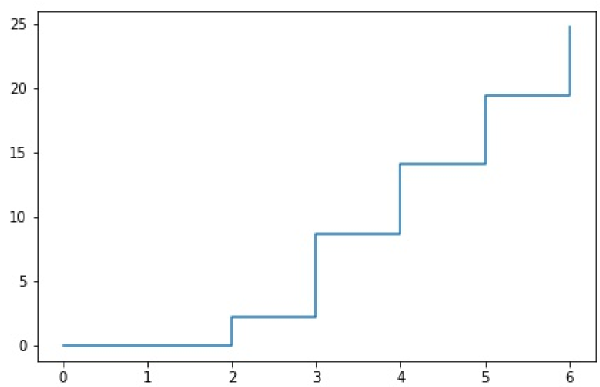
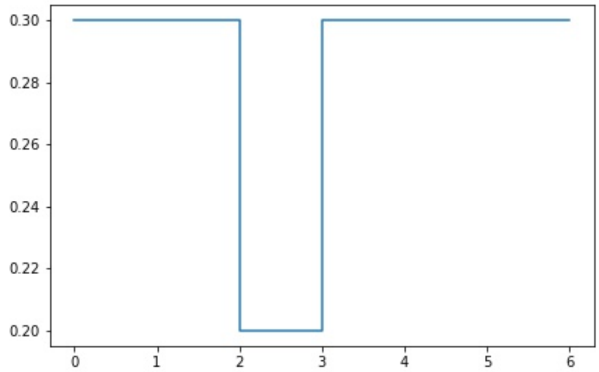
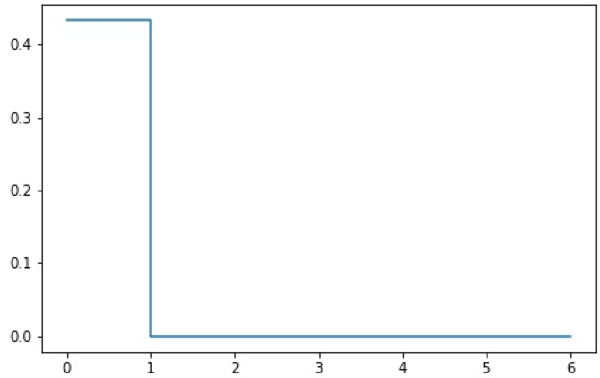


Figure 5: Temporary mortality decrease (no pension)

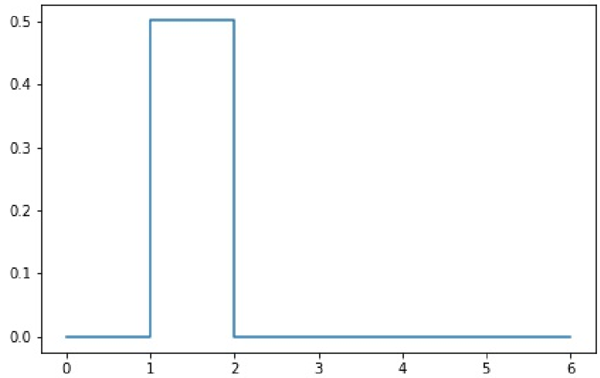
(a) Mortality



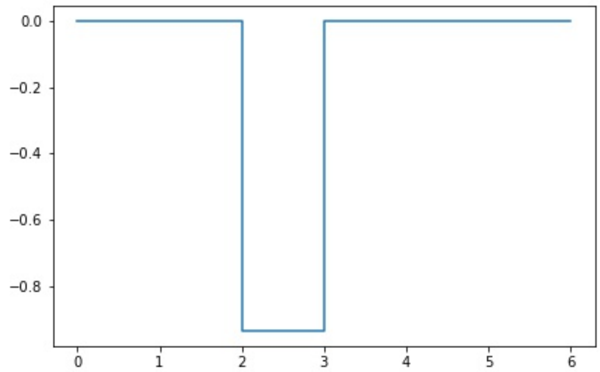
(b) Young-worker saving



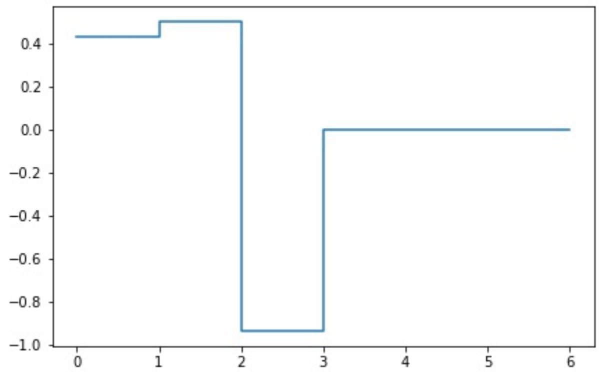
(c) Old-worker saving



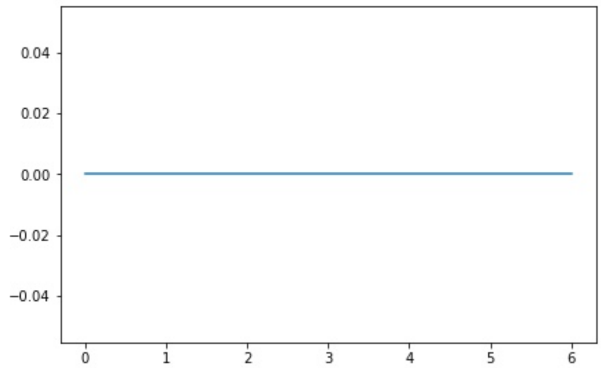
(d) Retiree saving



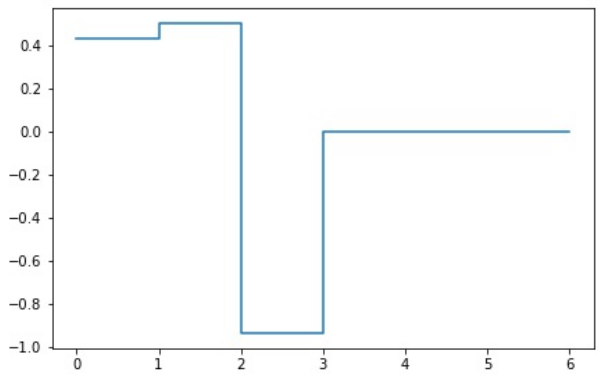
(e) National saving



(f) Investment



(g) Current account



(h) Net foreign assets

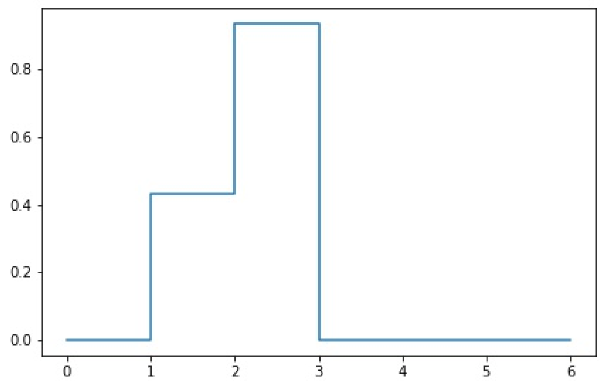
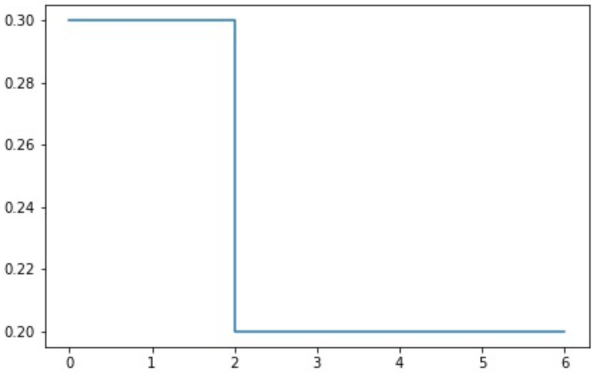
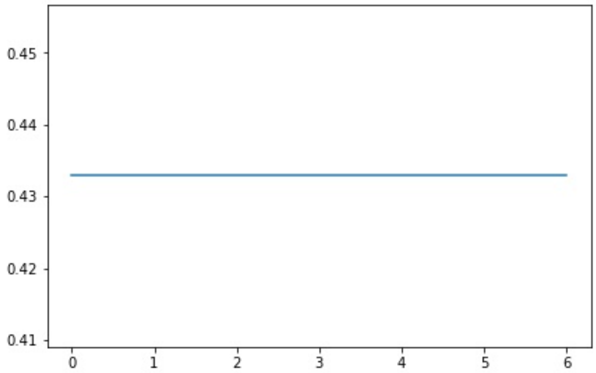


Figure 6: Permanent mortality decrease (no pension)

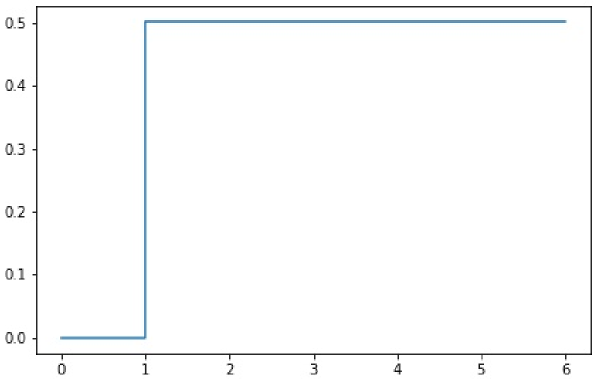
(a) Mortality



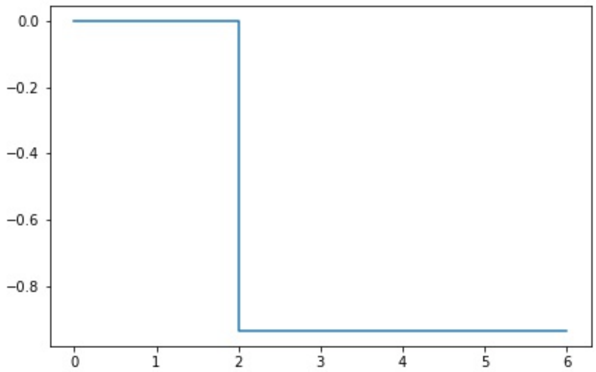
(b) Young-worker saving



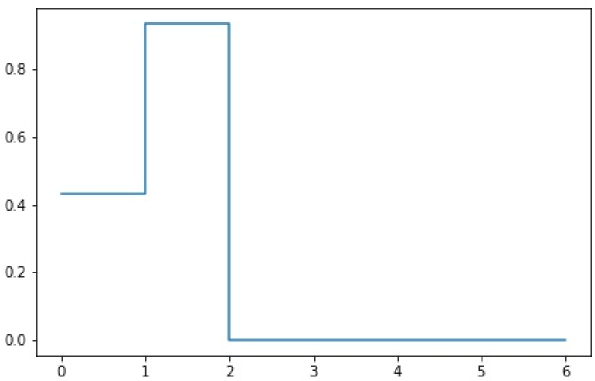
(c) Old-worker saving



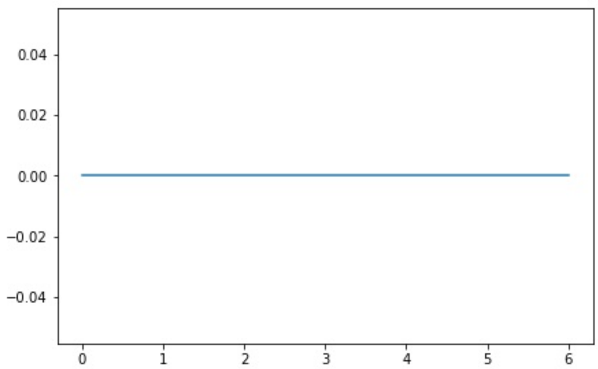
(d) Retiree saving



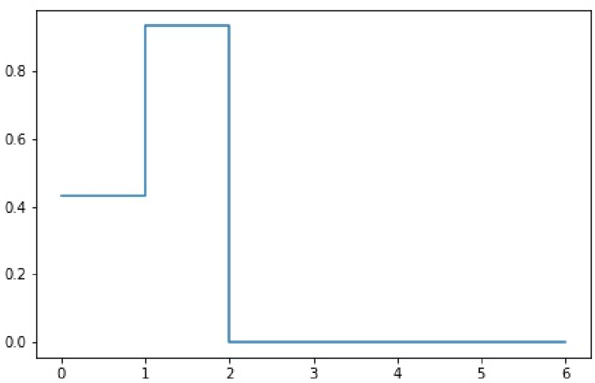
(e) National saving



(f) Investment



(g) Current account



(h) Net foreign assets

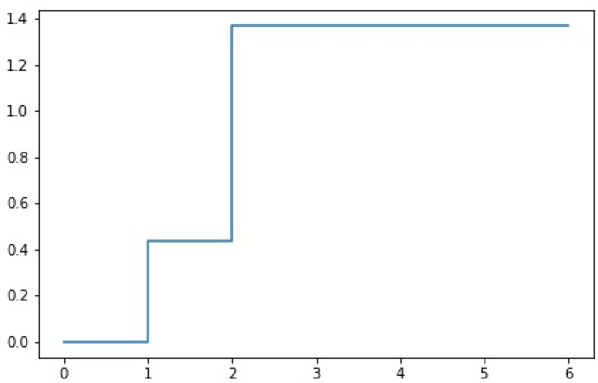
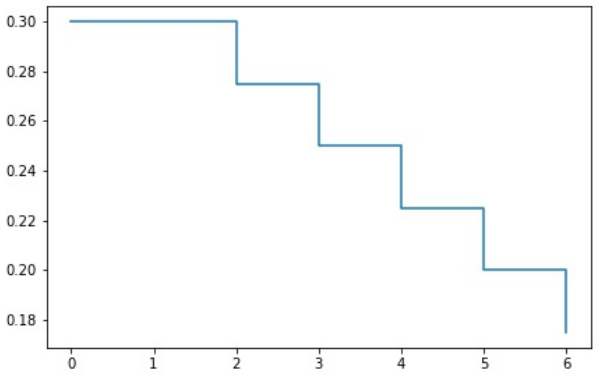
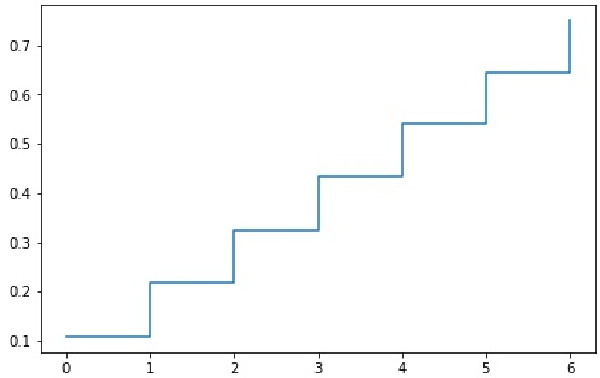


Figure 7: Persistent mortality decrease (no pension)

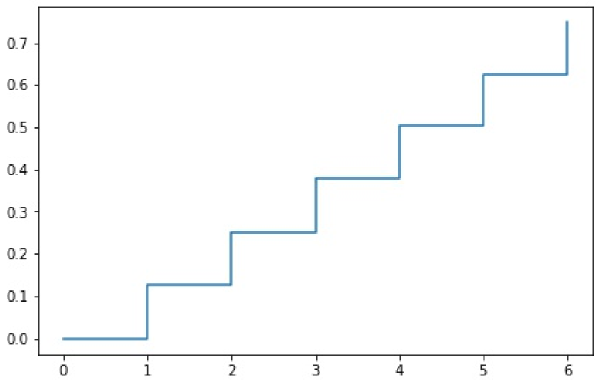
(a) Mortality



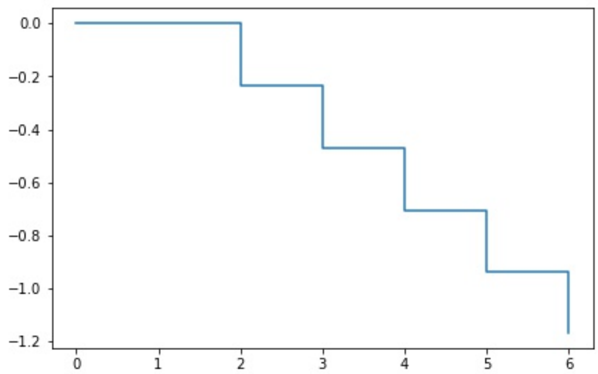
(b) Young-worker saving



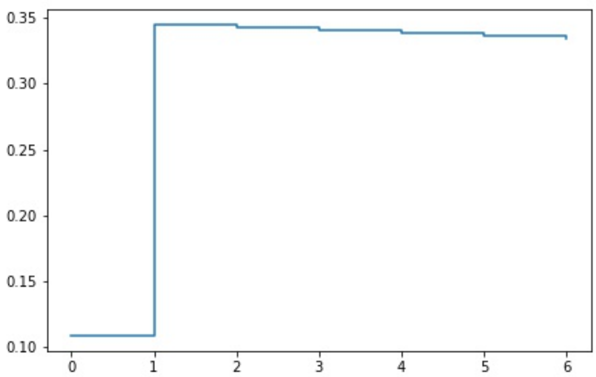
(c) Old-worker saving



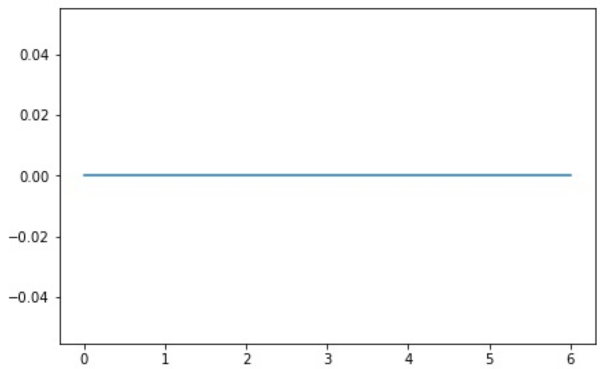
(d) Retiree saving



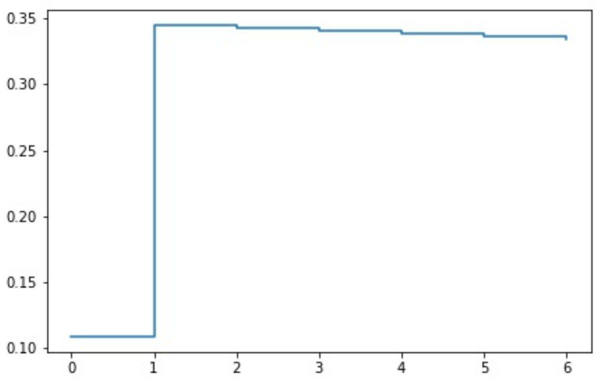
(e) National saving



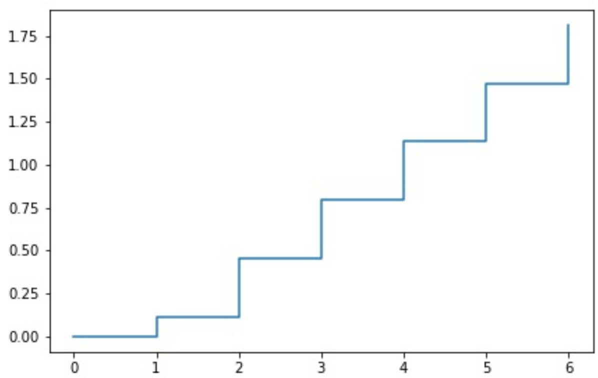
(f) Investment



(g) Current account



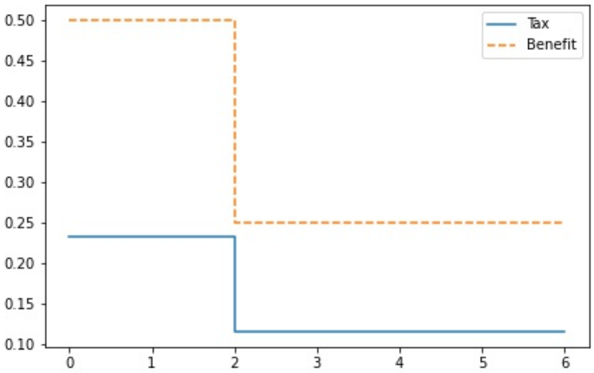
(h) Net foreign assets



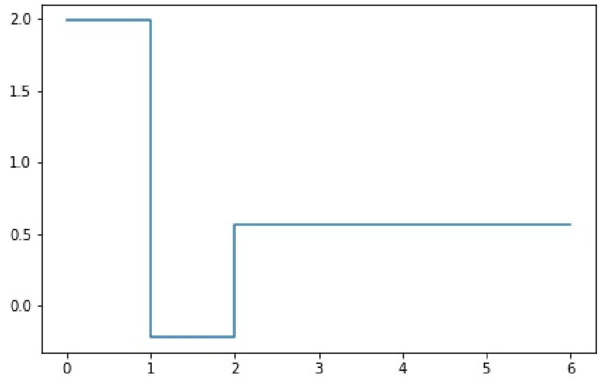
(2) Effects of demographic change and pension systems

Figure 8: Pension reduction without demographic change

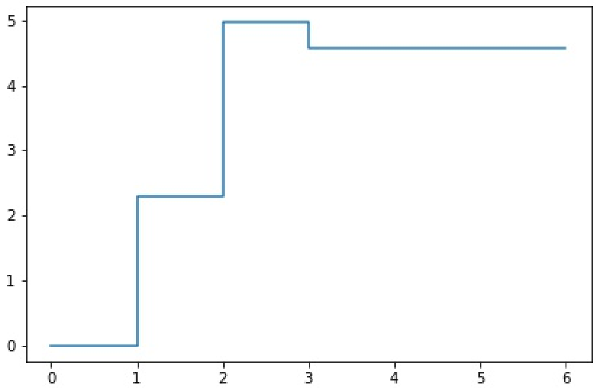
(a) Pension replacement rate



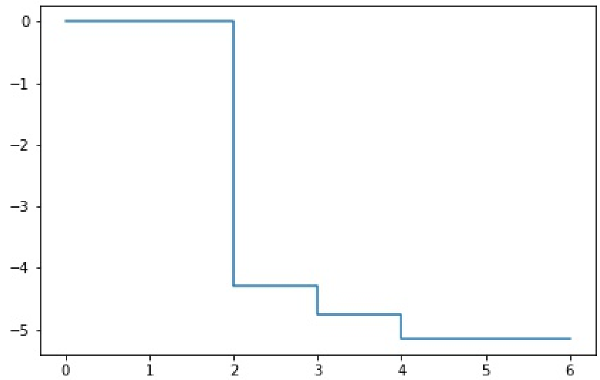
(b) Young-worker saving



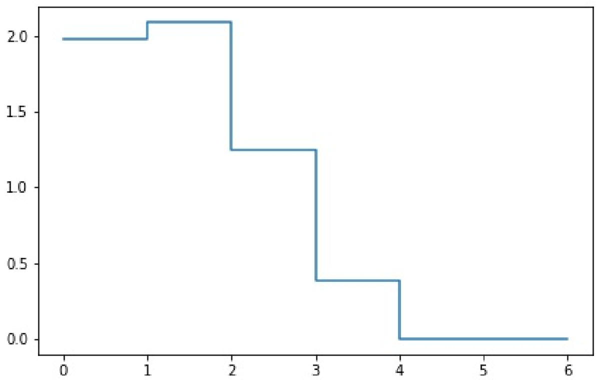
(c) Old-worker saving



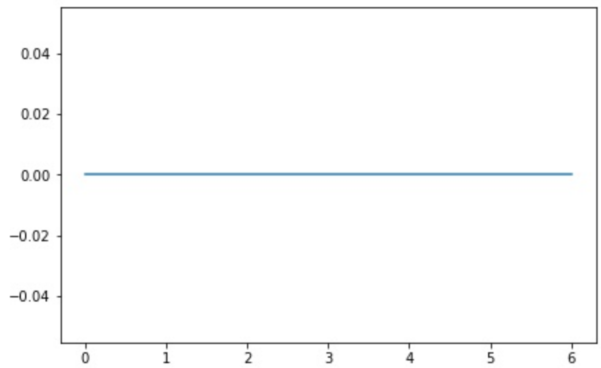
(d) Retiree saving



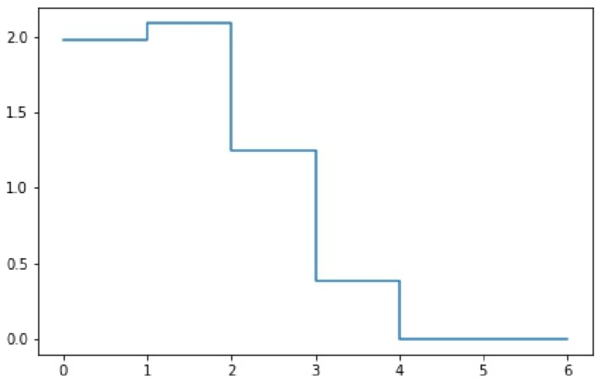
(e) National saving



(f) Investment



(g) Current account



(h) Net foreign assets

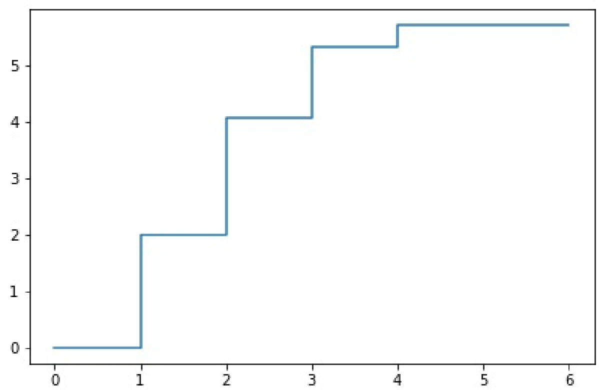
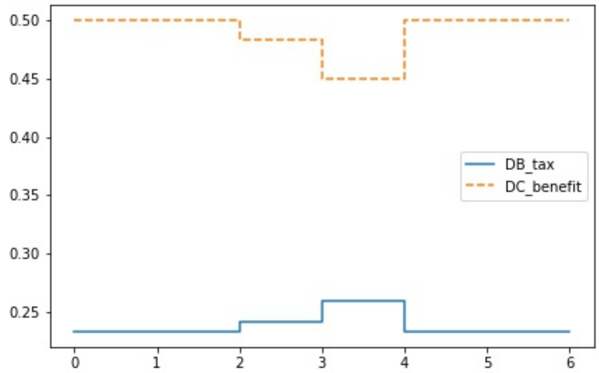
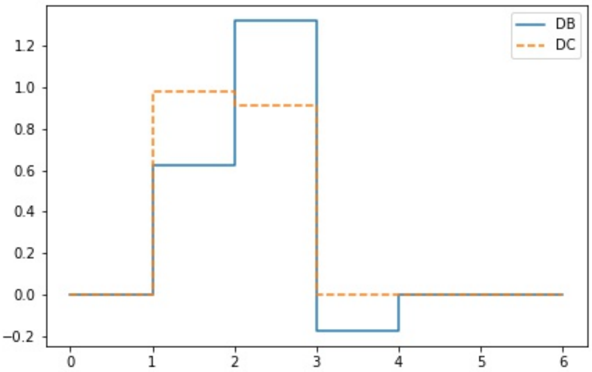


Figure 9: Temporary fertility decrease with pension system

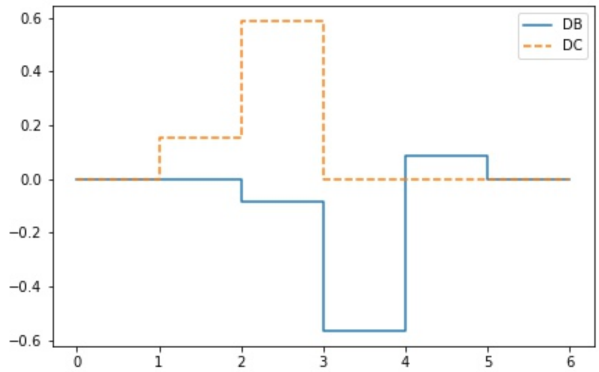
(a) Pension tax and benefit



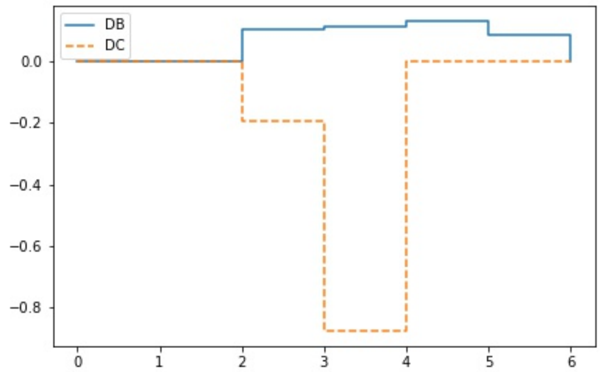
(b) Young-worker saving



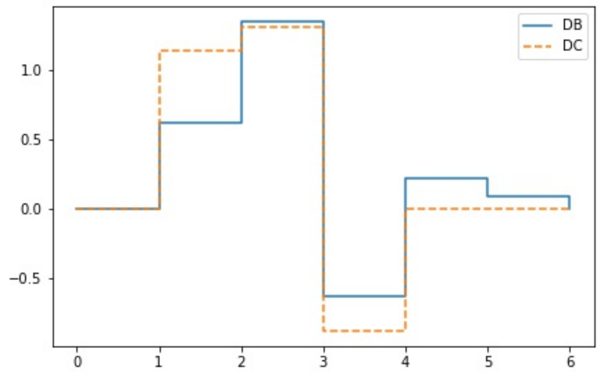
(c) Old-worker saving



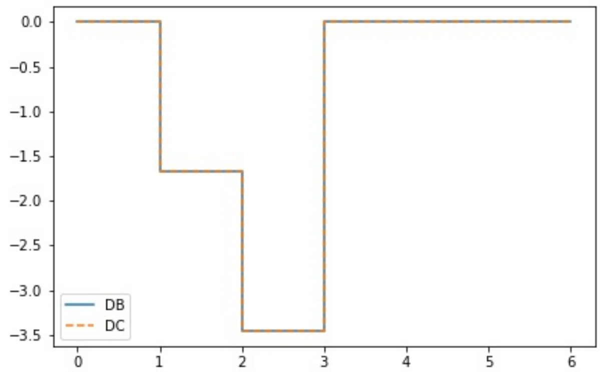
(d) Retiree saving



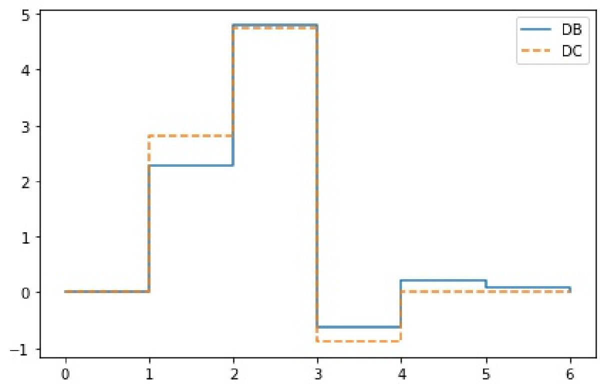
(e) National saving



(f) Investment



(g) Current account



(h) Net foreign assets

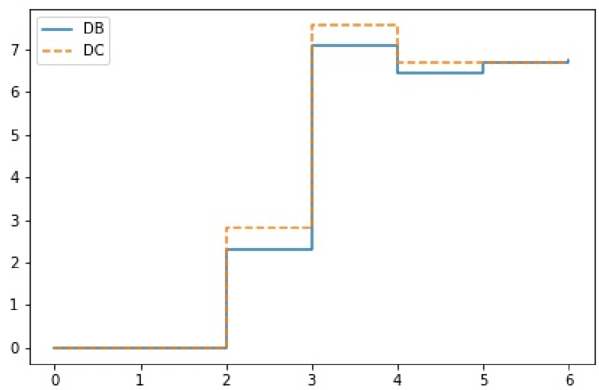
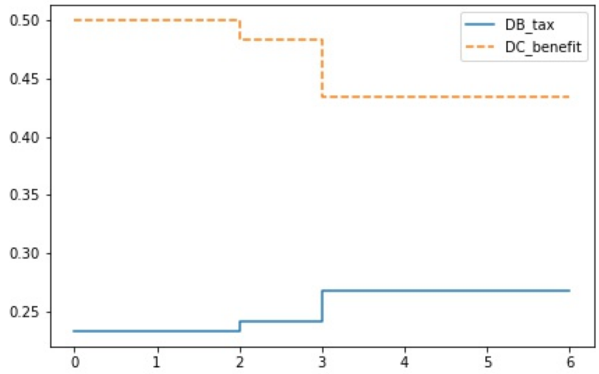
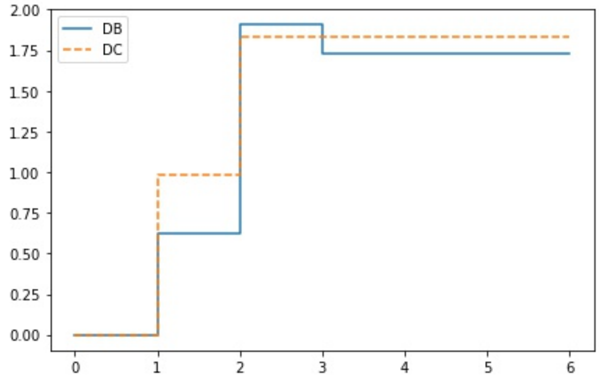


Figure 10: Permanent fertility decrease with pension system

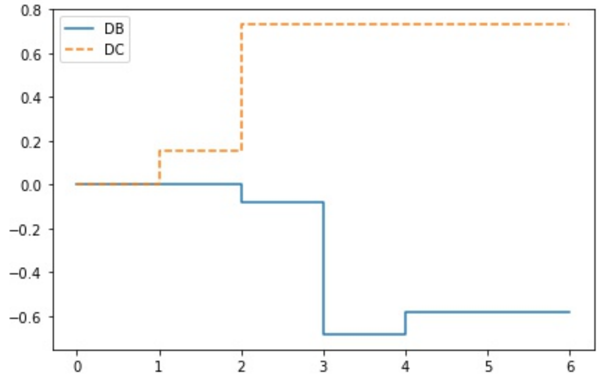
(a) Pension tax and benefit



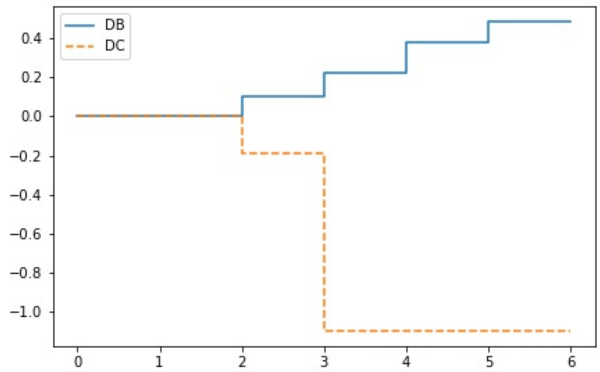
(b) Young-worker saving



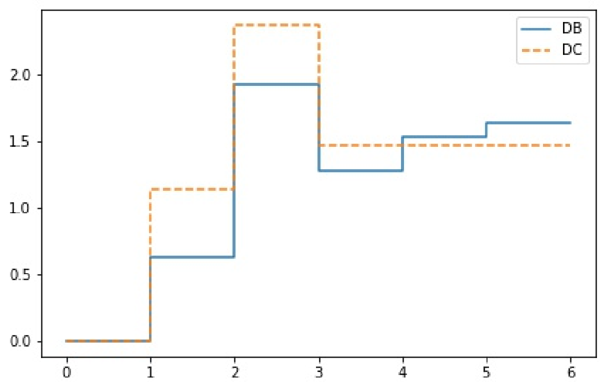
(c) Old-worker saving



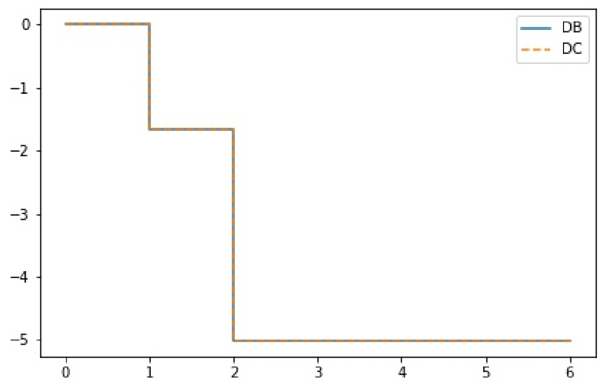
(d) Retiree saving



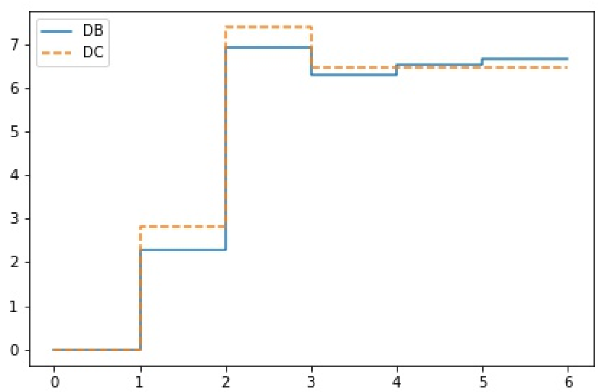
(e) National saving



(f) Investment



(g) Current account



(h) Net foreign assets

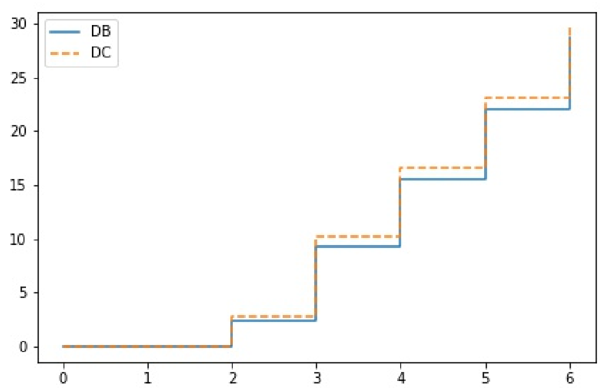
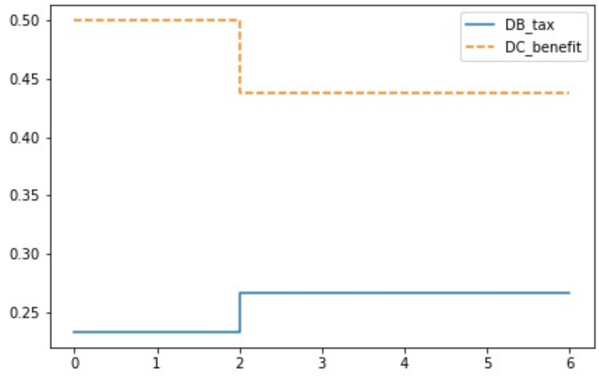
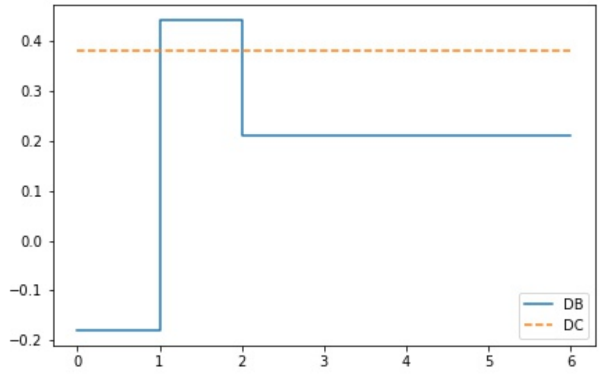


Figure 11: Permanent mortality decrease with pension system

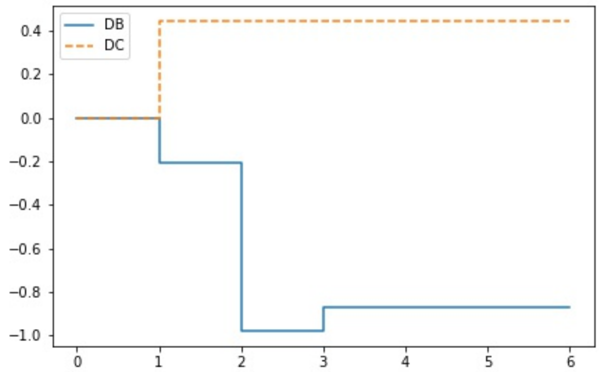
(a) Pension tax and benefit



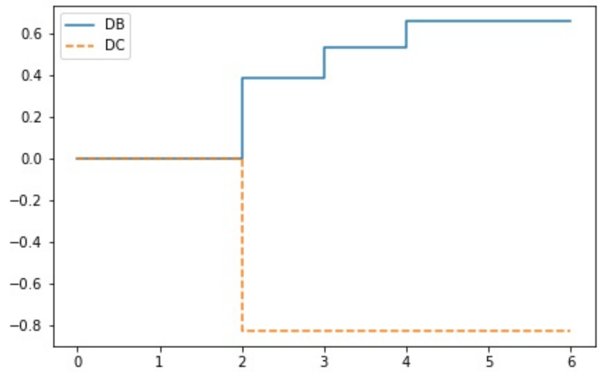
(b) Young-worker saving



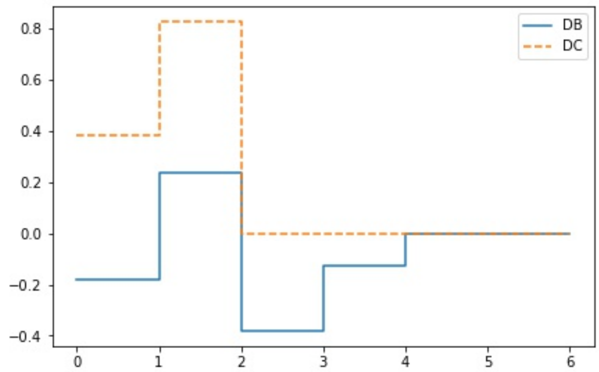
(c) Old-worker saving



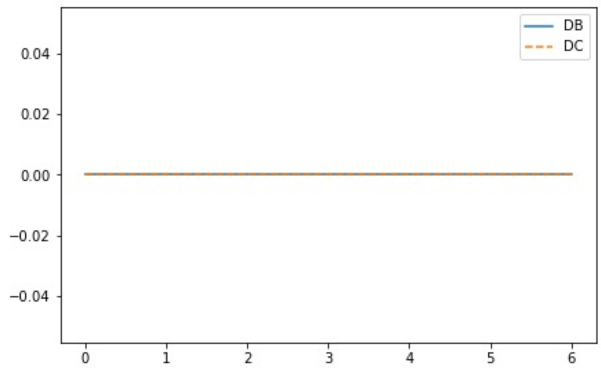
(d) Retiree saving



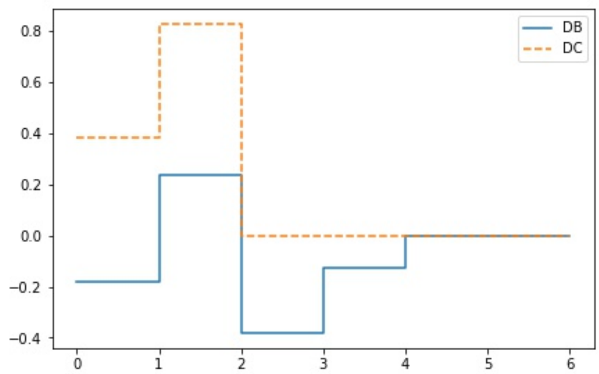
(e) National saving



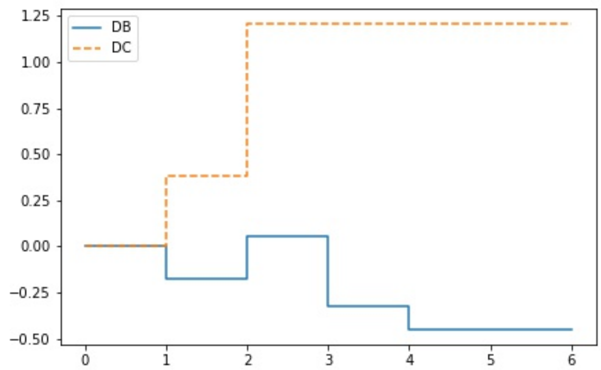
(f) Investment



(g) Current account



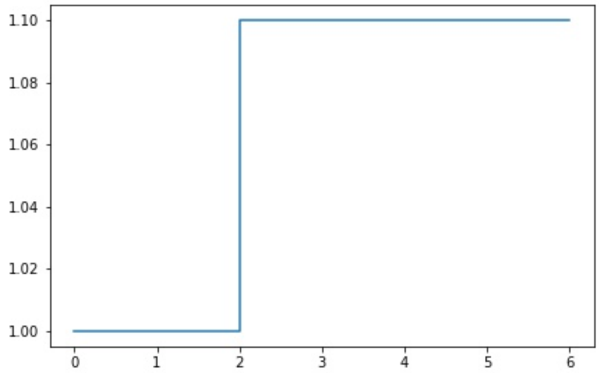
(h) Net foreign assets



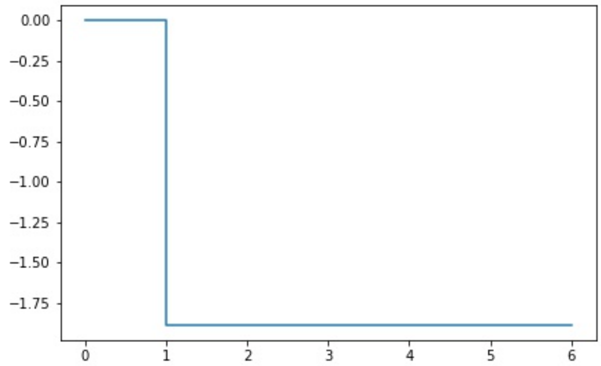
(3) Effects of demographic change and productivity growth

Figure 12: Persistent productivity increase without demographic change (no pension)

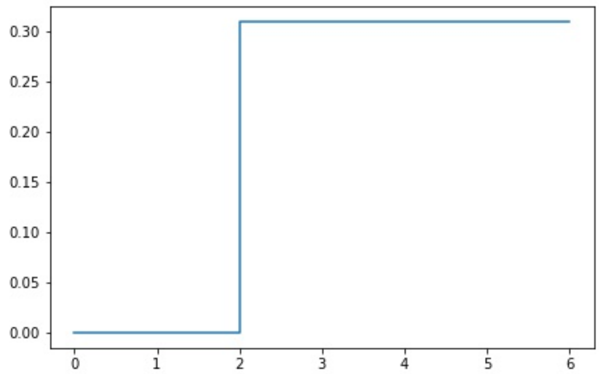
(a) Productivity growth



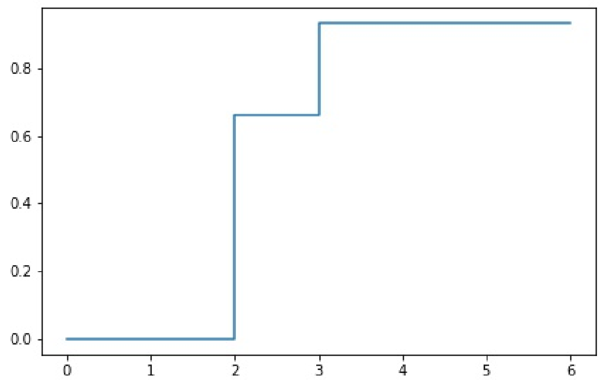
(b) Young-worker saving



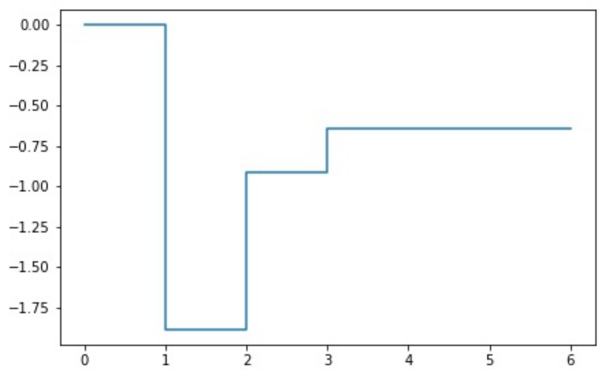
(c) Old-worker saving



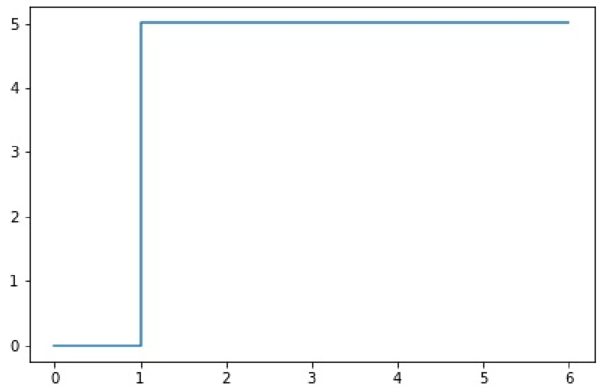
(d) Retiree saving



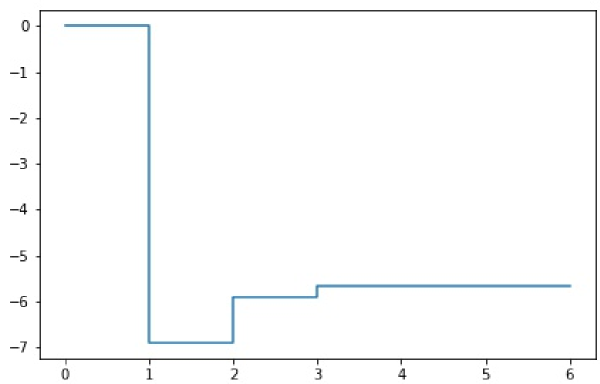
(e) National saving



(f) Investment



(g) Current account



(h) Net foreign assets

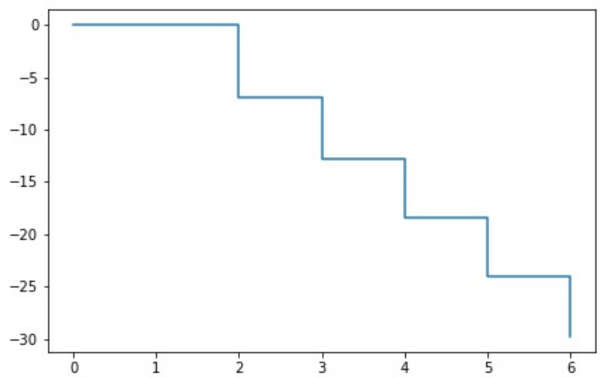


Figure 13: Permanent fertility decrease and persistent productivity increase (no pension)

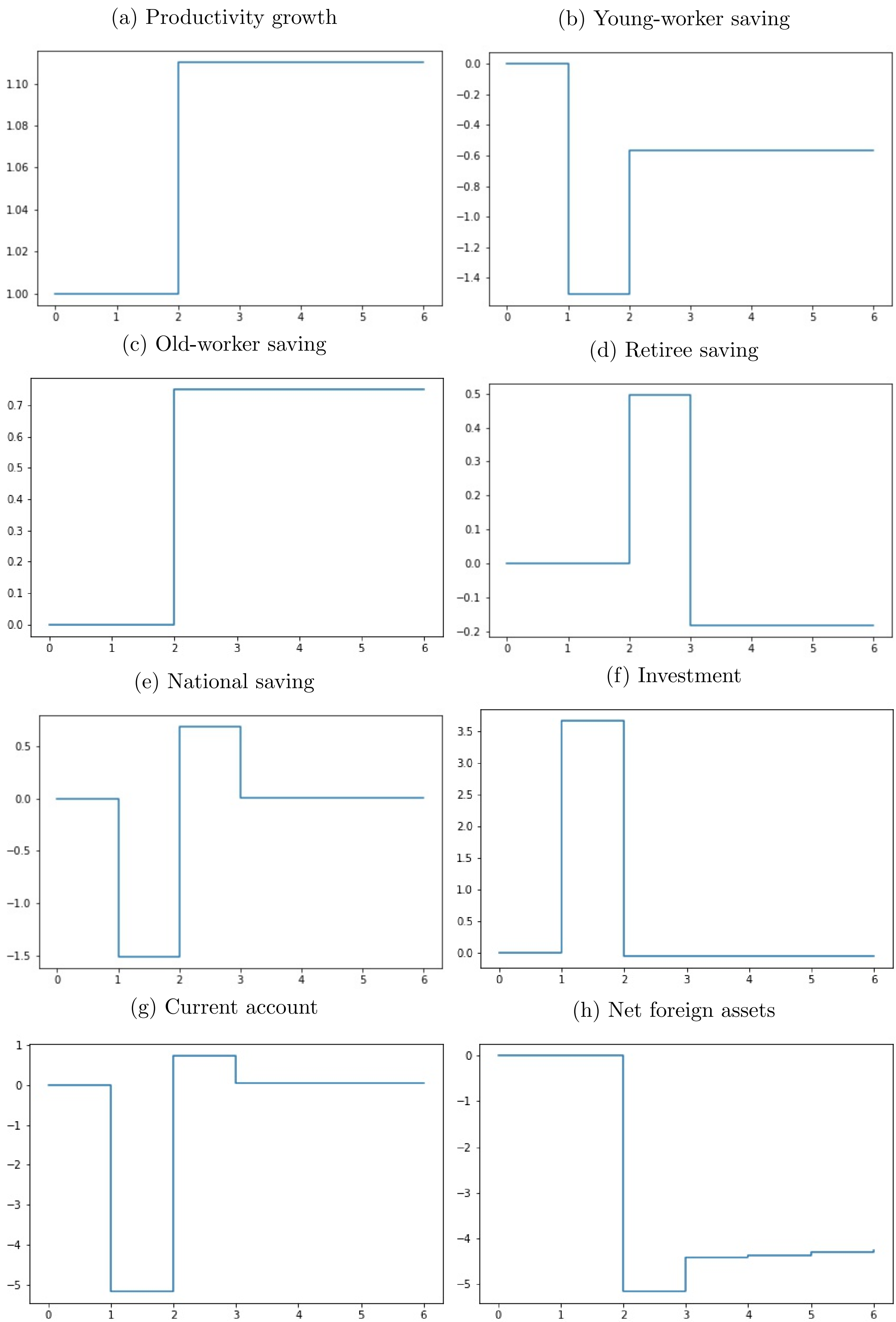
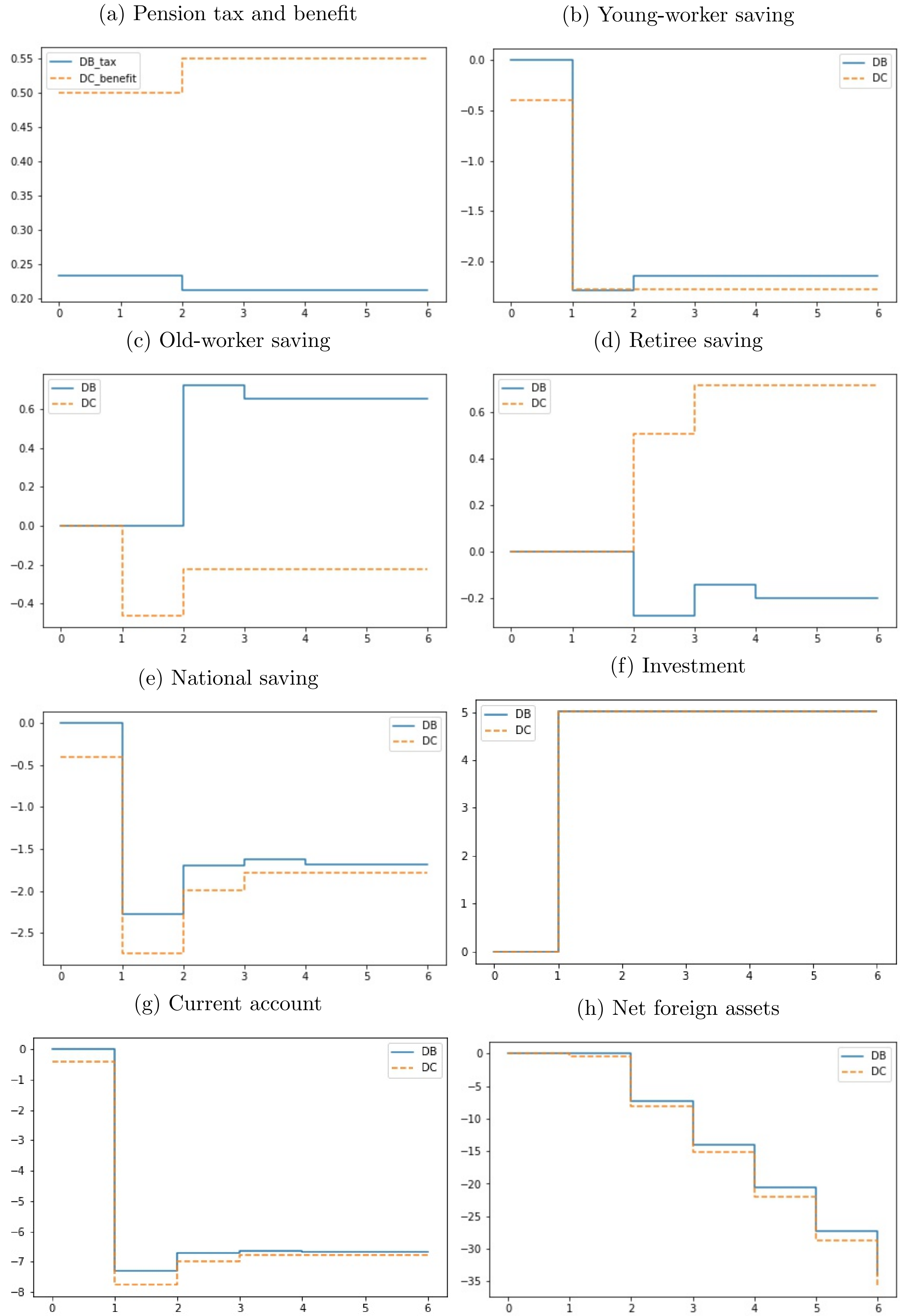


Figure 14: Persistent productivity increase with pension system (no demographic change)



(a) Pension tax and benefit

(b) Young-worker saving

(c) Old-worker saving

(d) Retiree saving

(e) National saving

(f) Investment

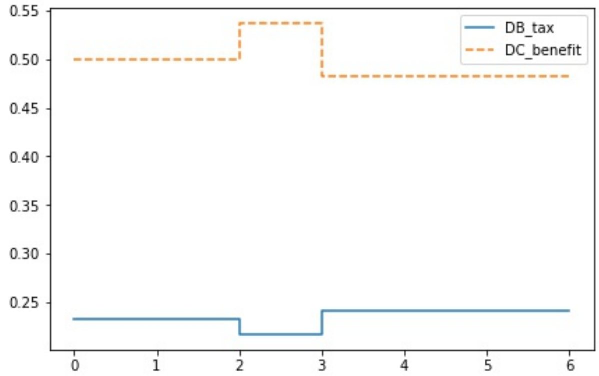
(g) Current account

(h) Net foreign assets

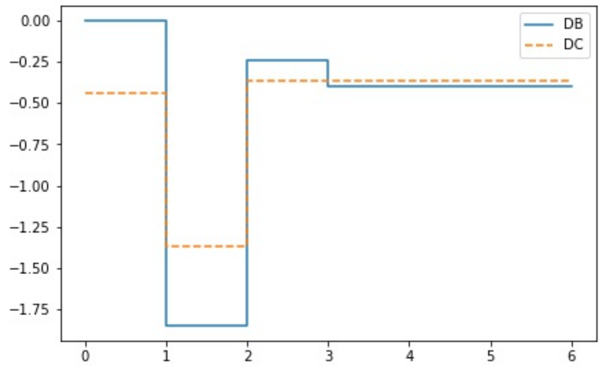
(4) Effects of demographic change, pension system and productivity growth

Figure 15: Permanent fertility decrease and persistent productivity increase with pensions

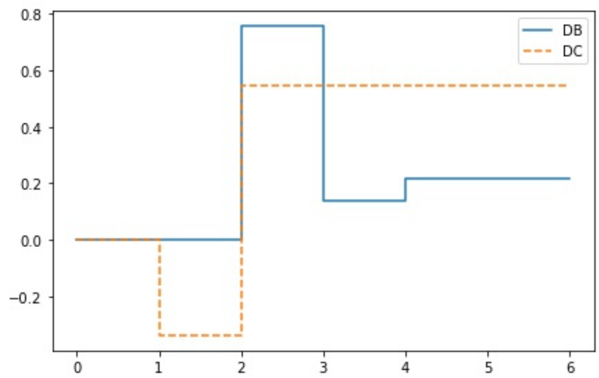
(a) Pension tax and benefit



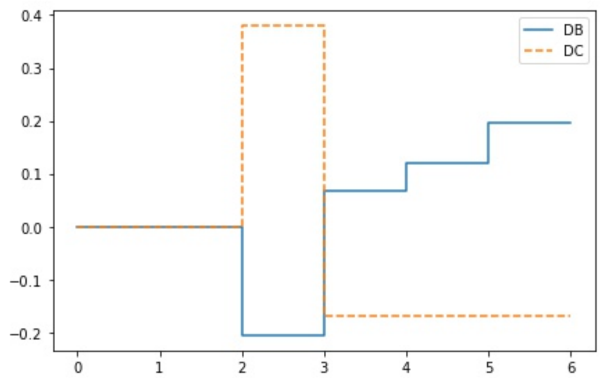
(b) Young-worker saving



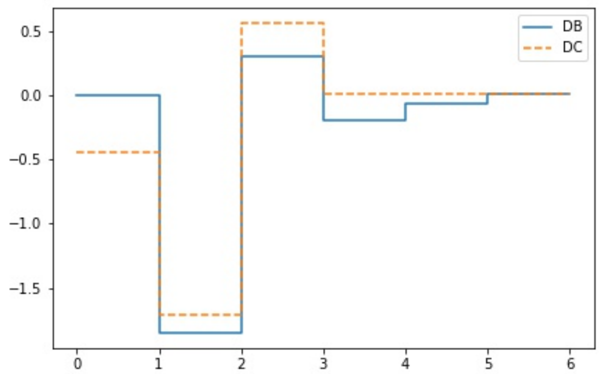
(c) Old-worker saving



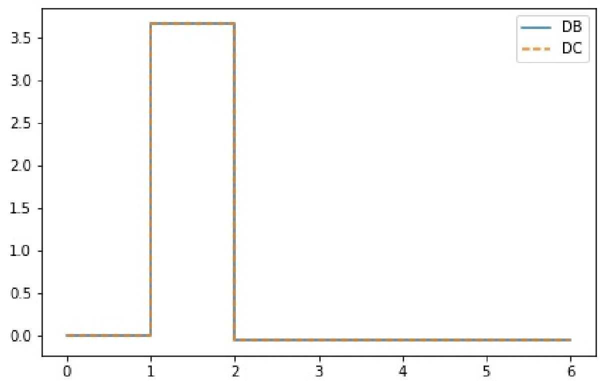
(d) Retiree saving



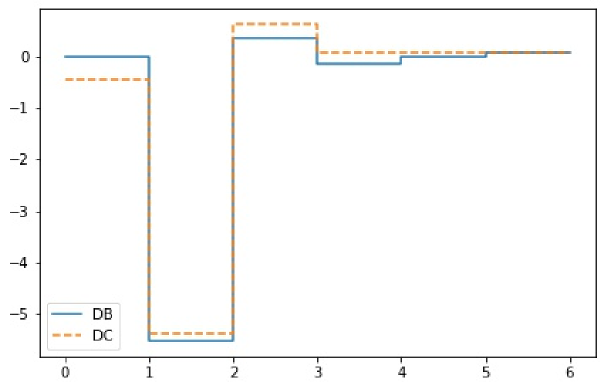
(e) National saving



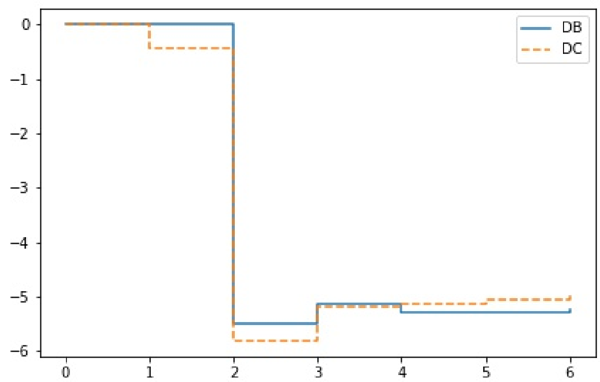
(f) Investment



(g) Current account



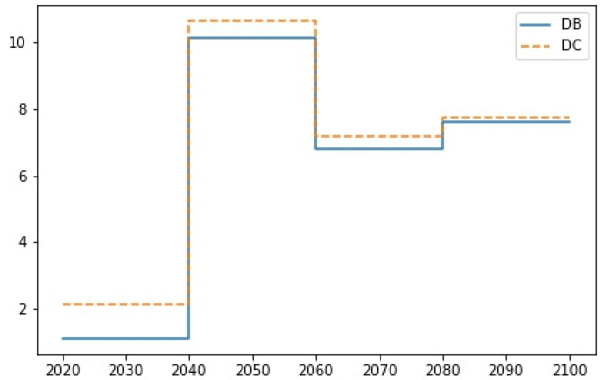
(h) Net foreign assets



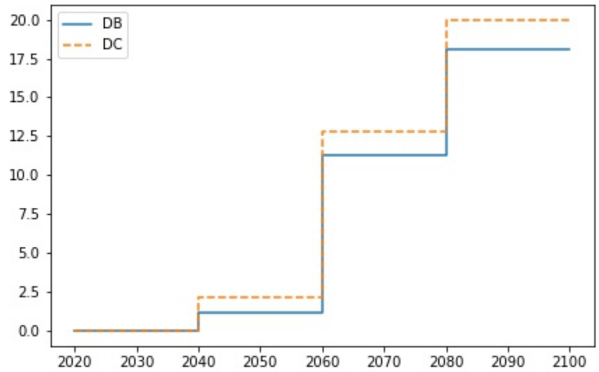
Appendix C: Quantitative results

Figure 16: Demographic impacts in four economies over 2020-2100

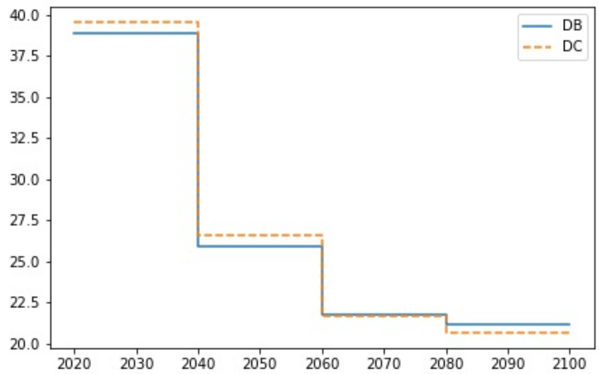
(a) US current account



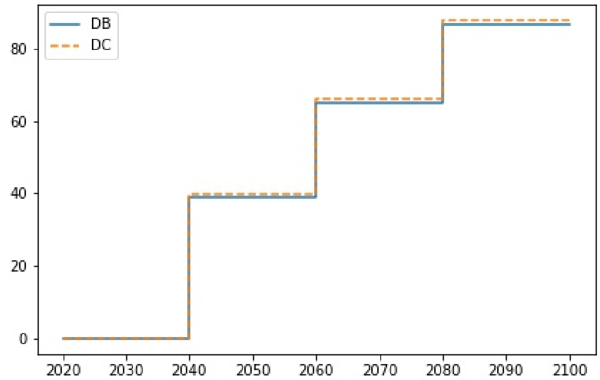
(b) US net foreign assets



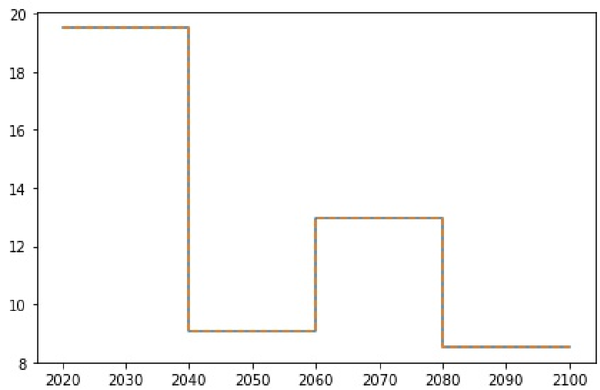
(c) Japan current account



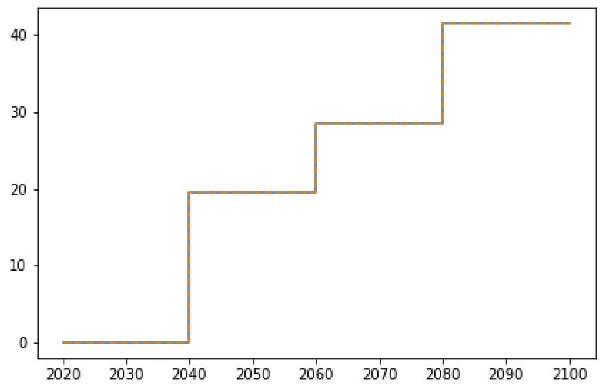
(d) Japan net foreign assets



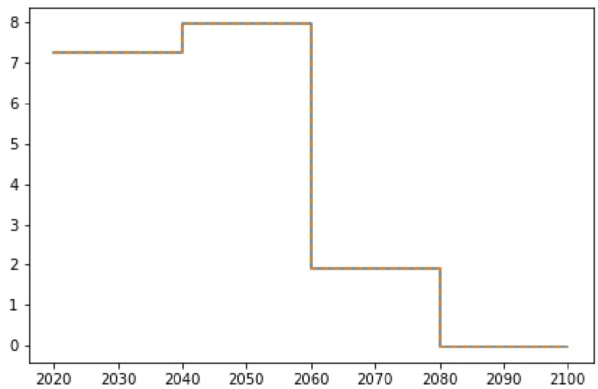
(e) China current account



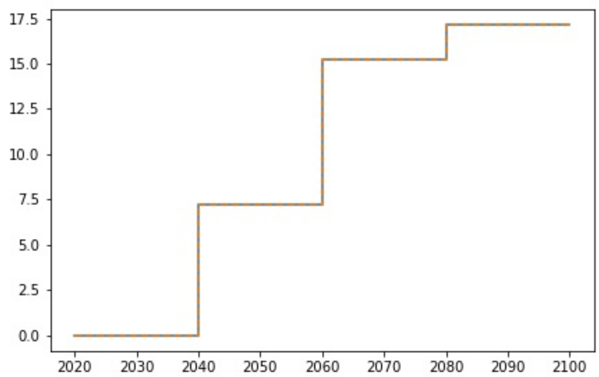
(f) China net foreign assets



(g) India current account



(h) India net foreign assets



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