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Weifeng Liu† and Warwick McKibbin‡

Abstract

The world has been experiencing dramatic demographic change since the 1950s, with almost all countries facing ageing challenges this coming century. However, the timing and speed of this demographic transition are significantly asymmetric across countries. This paper examines the impacts of global demographic change on macroeconomic conditions, international trade, and capital flows in major economies in a global multi-region and multi-sector general equilibrium model. We separately simulate demographic shocks in six regions of the world economy to understand how each shock individually affects the world economy and then combine these shocks to obtain the consequences of global demographic change. The paper finds that future demographic change will have significant impacts on each region's GDP, which will change the landscape of the world economy. However, the spillover effects on GDP across countries are relatively small. In young economies such as emerging Asia and Africa, while economic growth will significantly benefit from demographic dividends, demographic change does not improve per capita GDP. In ageing economies such as Japan and Europe, population ageing will decrease the real interest rate. However, this impact will be offset by rising interest rates in young economies. Due to the differential real interest rates, capital will flow from more ageing to less ageing economies. These capital flows can be substantial and beneficial for all economies.

Keywords: Global demographic change, consumption, investment, international capital flows, international trade, current account balances, DSGE, CGE, heterogeneous agents, G-Cubed

JEL Codes: C63, C68, F32, F41, E21, J11

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1. Introduction

The world has been experiencing dramatic changes in population growth and age structures since the 1950s, due to decreasing fertility rates and increasing life expectancy (Figure 1a and 1b). Population growth has been slowing globally and is forecast to decline further this century (Figure 1c). The growth rate was close to 2 per cent in the 1950s and reduced to around 1 per cent in the 2010s, and is forecast to further decline to around 0.5 per cent by 2050. The growth of the global working-age population (aged over 15-64) has also been decreasing since the 1980s. However, the size of the working age population will continue to increase until 2050, mainly driven by Asia and Africa (Figure 1d). Population structures have been ageing in most regions and are forecast to continue to age in all regions in the next several decades. The youth dependency (the ratio of population under 15 to population over 15-64) started to decline in the 1980s, and the elderly dependency (the ratio of population over 65 to population over 15-64) has increased quickly since the 2010s (Figure 1e and 1f). The global population over 65 is forecast to reach 0.7 billion by 2020 and 1.5 billion by 2050, representing 16 per cent of the world population.

While this demographic change is a worldwide phenomenon, regions and countries are significantly asymmetric in the timing and speed of this transition (see McKibbin 2006). Advanced economies such as Japan and Europe have been ageing rapidly while developing countries are relatively young. Most developing countries are also experiencing similar patterns of demographic change, but their transitions occur several decades after those ageing pioneers. For example, European population growth has been much lower than the world average, and the growth rate is already close to zero, with the working-age population declining since 2011. In contrast, Africa's population has grown strongly since 1950, and its growth rate is still as high as 2.5 per cent. More than half of global working-age population growth will come from Africa over the period 2020-2050. Asia and Latin America have experienced similar declines in population growth, and their working-age populations are both expected to increase until the 2040s before starting to decline.

The demographic transitions have significant impacts on domestic macroeconomic conditions, whereas the demographic asymmetry across countries is important for the cross-border effects of demographic change. As the world has increasingly become integrated and connected, the demographic effects in open economies are more complicated when demographic change is unsynchronized and production factors (capital, labor, and commodities) are mobile to various

extents across countries. There is an emerging literature investigating the international aspects of demographic change. Most studies of open economies show that cross-border effects of demographic change through the channels of international trade and capital flows can be significant. The fundamental rationale is that demographic change affects aggregate savings and investment through changing the relative size of age cohorts because age cohorts differ in saving rates and labor productivity. In closed economies, national savings and investment must move together through the adjustment of the real interest rate. But in open economies, when the shifts in national savings and investment affect domestic real interest rates, arbitrage forces in the world capital markets drive international capital flows, which allows domestic savings and investment to move somewhat independently. This adjustment causes the current account to move into either surplus or deficit. These spillovers change macroeconomic conditions and external balances for both domestic and foreign economies. The scale of adjustment depends on the openness and size of economies as well as the relative size of demographic shocks.

As demographic change can affect current account balances, it is possibly an important driver of global imbalances. Since the 1990s, current account deficits and surpluses have been increasing persistently around the world. In particular, the United States has run persistent current account deficits while Asia has run large surpluses. The global imbalances have raised concerns about long-term financial stability and resilience of the world economy, and they have also triggered the recent trade disputes between the United States and other countries. The G20 and the IMF thus call for research on the drivers of global imbalances (IMF 2019).

Against this global background of demographic change and current account imbalances, this paper examines the global macroeconomic impacts of the worldwide demographic change over the next several decades. Our contribution is four-fold. First, we build a multi-region multi-sector general equilibrium model designed for analyzing global demographic scenarios. The model covers all countries in the world and aggregates them into eighteen countries and regions. Thus the model is suitable to investigate the current demographic transition, which is a worldwide phenomenon. Second, the model has disaggregated sectors and thus incorporates sectoral adjustments. Shifts in the sectoral composition of economies, due to demographic shocks, is important because of different intensities of capital relative to labour across sectors and countries. Third, our model incorporates important short-run rigidities such as adjustment costs in physical capital accumulation, wage stickiness and monetary policy rules. Rigidities and policy responses allow us to capture short- and medium-term dynamic adjustments which are difficult to be analyzed in most long-term life-cycle models. The model also has a full menu

of financial assets which can have impacts on the real economy in the short run in the face of economic shocks. The model also incorporates heterogeneity in households and firms by modeling households and firms with a mix of both forward-looking and backward-looking behavior. This deviation from fully forward-looking optimizing behavior creates additional dynamics compared to other models. Fourth, we can simulate a global demographic shock in the model and further decompose the shock into regional shocks. The capacity to decompose shocks makes it easier to understand how each shock individually affects the world economy. In contrast with most demographic studies which focus on developed countries, we investigate both developed and developing countries and particularly show the impacts of demographic advantages in emerging Asia and Africa on their economies and also on the world economy.

This paper finds that demographic-driven capital flows from more ageing to less ageing countries can be substantial. This pattern of capital movements is beneficial for young economies to finance productive investment, and also favorable for ageing economies to reap higher rates of return on capital than would be available in autarky situations. The paper also suggests that population ageing would decrease the real interest rate in ageing economies. However, this reduction would be substantially offset globally due to an increase in the real interest rate in young economies such as emerging Asia and Africa. These growing economies would attract significant capital from the world market. The results that demographic change in different economies produce both upward and downward pressure on real interest rates suggests that the studies on demographic change in closed economies are likely to miss important spillover effects on capital flows and international trade. However, the spillover impacts on GDP are quite small because the impacts of capital flows on investment and trade balances go in opposite directions. Demographic change has significant impacts on domestic GDP, so the asymmetric demographic change would significantly change the landscape of the world economy. In particular, under certain assumptions, emerging Asia and Africa could enjoy significant demographic dividends. Demographic change is beneficial for economic growth in developing economies, but it does not improve per capita GDP, because higher output per work is offset by an increase in the number of elderly people in the population. The results also show that international capital flows can avoid significant contractions in consumption that would otherwise occur in ageing countries. Consumption responds much more smoothly than production because capital can move around the world to earn higher rates of return in response to demographic shocks in ageing counties, avoiding significant income declines.

The paper is structured as follows. Section 2 provides a literature review. Section 3 introduces the model and particularly the approach of incorporating life cycle features. Section 4 shows the demographic scenarios, and Section 5 presents the main results. Section 6 concludes.

2. Related Literature

Many studies show that the cross border effects of demographic change can be significant. Bryant and his coauthors (Bryant 2004a; Bryant and De Fleurieu 2005; Bryant and McKibbin 1998; Bosworth et al. 2004) provide reviews of early studies on macroeconomic effects of demographic change in open economies, highlighting the importance of cross-border effects of asymmetric demographic change across countries. Bryant and McKibbin (2004) introduce demographic change following the approach of Blanchard (1985) into two general equilibrium models of infinitely-lived representative agents (a two-region IMF MULTIMOD model and a two-region MSG3 model). They show that differences across countries in the timing and intensity of demographic change can have significant effects on exchange rates, international trade and capital flows. Borsch-Supan and his coauthors (Borsch-Supan et al. 2001, 2006; Borsch-Supan and Winter 2001; Borsch-Supan and Ludwig 2010; Borsch-Supan et al. 2014) investigate demographic change in multi-country overlapping-generation models. They show that capital flows from fast-ageing industrial countries to the rest of the world are substantial, and argue that studies on demographic change in closed economies are likely to miss important effects of international capital flows. Attanasio et al. (2016) show that capital mobility can attenuate some negative impacts of demographic trends in developed regions and can lead to important welfare gains in both developed and developing regions. A large difference in interest rates across regions that would prevail in closed economies could induce significant capital flows between open economies, changing factor prices, tax bases, and fiscal conditions of each region.

There is a consensus on the patterns of demographic-driven capital flows. While the decrease in the labor force in more ageing countries reduces the marginal product of capital, the increase in the labor force in less ageing or still growing countries raises the marginal product of capital and hence leads to higher investment. This asymmetry would stimulate capital flows from more rapidly to less rapidly ageing countries to finance productive investment. From a geographic perspective, the existing studies fall into two broad streams. One stream focuses on OECD countries and shows that considerable capital flows would emerge between OECD countries due to asymmetric ageing processes within OECD. Cutler et al. (1990) show that demographic

change in rapidly ageing OECD countries can drive capital flows into the United States, and the latter responds with higher consumption than in the autarky situation, leaving current account deficits. Faruqee (2002) also finds that demographic change drives capital flows from Europe and Japan to the United States based on the IMF MULTIMOD model. Henriksen (2002) argues that demographic change can well explain the current account dynamics between the United States and Japan since 1970. Feroli (2003) shows that demographic differences among seven industrialized countries can explain some observed long-term capital movements within the group and particularly predict the size and timing of American current account deficits and Japanese current account surpluses. Domeij and Floden (2006) also show that demographic change explains a significant fraction of capital flows between OECD countries since 1985. Borsch-Supan et al. (2001) show that the effects of population ageing on capital markets are strong within European economies.

The other stream of research takes developing countries into account. As developed countries are ageing faster than developing countries, the demographic divergence could stimulate capital flows from OECD countries to emerging and developing countries. Borsch-Supan et al. (2001) show that capital flows from fast ageing industrial countries to the rest of the world are substantial. Brooks (2003) finds that retirement saving by ageing baby boomers would substantially increase capital supply in Europe and North America, causing large capital exports to Africa, Latin America and other emerging markets. McKibbin (2005, 2006) and Batini et al. (2006) incorporate demographic dynamics into the MSG3 model of the global economy. They find that capital would flow from Japan to developing regions, leaving current account surpluses in Japan for several decades. The trade balance would gradually move from surplus to deficit as financial incomes from abroad are increasing repatriated to Japan for retirement consumption. Backus et al. (2014) show that demographic differences can account for the pattern of capital flows between the United States, Japan, Germany and China. Attanasio et al. (2016) show that there are large capital inflows from high-income ageing countries to China due to unsynchronized demographic transitions in an overlapping-generation model of four regions.

Capital flows across countries, particularly between developed and developing countries driven by demographic change are overall reciprocal for both groups of economies. As capital per worker in developing countries is generally much lower than in developed countries, 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) are in favor of globalization as a way of countries handling the international aspects of population ageing, arguing that if large capital flows to developing countries could occur, net benefits would accrue to both developed and developing countries. The world could experience increased convergence in regional income and wealth. Bryant (2004a) argues that economic openness fosters a partial sharing of demographic shocks with the rest of the world and mitigates the negative consequences of population ageing on domestic output and consumption. A large negative demographic shock would cause major negative effects on aggregate output and consumption, but aggregate consumption is significantly above the autarky level. Attanasio and Violante (2000) and Attanasio et al. (2006) simulate global demographic changes with two regions of the world (developing and developed regions) and show that the demographic transition can improve per capita income above the autarky levels in both regions for several decades. Without international capital flows, the demographic transition would be costly for developed regions. Attanasio et al. (2016) show that large capital inflows to China due to unsynchronized demographic transition can generate major welfare gains. However, the subsequent reversal of capital flows can reduce the gains.

There are both winners and losers in each economy due to international capital flows. In general, workers would be harmed with lower wages in old countries when capital flows out, and capital owners in young countries are faced with lower rates of return on capital when capital flows in. Krueger and Ludwig (2007) find that rates of return decline and wages increase by more in the open economy than in autarky for the United States. When capital flows into the United States from rapidly ageing OECD countries, young workers gain from higher wages while old asset owners lose in the United States.

While emerging markets and developing countries can provide investment opportunities, they may not be able to absorb enough of the OECD savings to dramatically change the saving-investment balance for the OECD as a whole for two reasons. First, investment outside the OECD brings potentially higher rates of return, but it requires developing countries to make major progress in macroeconomic management and financial stability. Second, developing countries will also experience similar ageing processes, and the marginal product of capital would also decline eventually in developing countries, making the investment in those regions less attractive over time. Bryant (2006, 2007) argue that the pattern of capital flows from developed to developing countries implied by the demographic change over this period, is plausible between 1950 and the mid-1970s. However, demographic forces are likely to diminish rather than augment this pattern after the 1970s because the relative speed in ageing

between the two regions has been changing. The ageing processes are accelerating in developing regions but decelerating in developed regions.

Most early studies focus on the above pattern of capital flows from developed to developing regions, but this pattern may have started to reverse in the 2010s. Some studies argue that this pattern would reverse when post-war baby boomers in developed countries, retire between 2010-2030 and start to dissave. Brooks (2003) predicts that baby boomers in Europe and North America will dissave in retirement beyond 2010, causing both regions to become capital importers. This shift to capital importing will be financed by capital flowing from Latin America and other emerging markets. Africa will remain dependent on foreign capital because of continued high population growth. The overall pattern in developing countries is to be initially dependent on foreign capital, followed by large capital exports towards the end of the transition. This pattern reflects population trends in industrial regions, where the ageing population consume their wealth over retirement.

The magnitude of capital flows depends on the openness and the relative size of countries. Since the 1980s, global financial markets have been increasingly integrated not only within OECD countries but also between advanced and emerging economies (Blanchard 2002). Attanasio et al. (2006) highlight that the effects of demographic trends for developing regions depend on the degree of international capital mobility and on the extent to which there is reform of pension systems in developed regions. When looking ahead, the relative size of countries depends on relative future productivity. Brooks (2003) and Batini et al. (2006) show that productivity assumptions can significantly affect capital flows and current account balances.

Fiscal sustainability of pension systems is a central topic in population economics. Some studies show that pension system reforms can have important impacts on international capital flows which, in turn, influence the effects of the policy reforms. Bryant (2004b) shows that alternative ways of operating pension systems and managing government debts can lead to substantially different macroeconomic outcomes. Borsch-Supan et al. (2001) show that population ageing and pension reforms have profound effects on international capital markets in Europe. Capital flows from rapidly ageing regions to the rest of the world can initially be substantial, but the trends are likely to be reversed when retirees decumulate savings. This process is amplified when a pension reform shifts public pension provision towards more private funding. Attanasio et al. (2007) examine the sustainability of pension systems in developed economies in a two-region model of the world economy (developing and developed)

and show that closed and open economies require similar fiscal adjustments for pension sustainability. However, the two cases diverge significantly in factor prices, aggregate variables and welfare. Fehr et al. (2003, 2008) develop an overlapping-generation model of three regions (the United States, Europe and Japan) to examine fiscal implications of demographic trends, and show that unsynchronized demographic change in the three regions induces major capital flows from Europe and Japan to the United States.

There is less consensus about the size and timing of effects because those multi-country models differ in their region coverage, model structures, assumptions and calibration, and population shocks.

In addition to the studies based on structural models, some empirical studies examine the historical effects of demographic change on current account balances in econometric models based on cross-country panel data. Higgins (1998) finds strong demographic effects on both national savings and investment and hence on the current account balances based on panel regressions. He argues 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. Bosworth (2004) also use panel regressions to estimate the effects of increased life expectancy on saving rates and investment rates. Kim and Lee (2008) use a panel vector autoregressive model to show that an increase in the dependency rate significantly lowers saving rates and worsens current account balances. Both saving and investment rates decline, but the decline of investment rates is far smaller than that of saving rates, which pushes down the real interest rate and worsens the current account.

3. The Hybrid DSGE/CGE Global Model

For this paper, we build a global intertemporal general equilibrium model with heterogeneous agents. This model is a hybrid of dynamic stochastic general equilibrium (DSGE) models and computable general equilibrium (CGE) models. We follow the approach in the G-Cubed model (McKibbin and Wilcoxen 1999, 2013) and make two contributions to the further development of the G-Cubed model. We model a different set of countries to the original G-Cubed model and incorporate demographic characteristics into the model.

(a) The G-Cubed Model

This new model has six sectors and eighteen countries and regions (hereafter regions). Table 1 presents all sectors in the model. The model is based on the input-output tables in the GTAP

database (Aguiar et al. 2016) and therefore differentiates sectors of production. Each sector in each country has different capital-labour ratios.

Table 1 Model Sectors

Sector Numbers	**Sectors**
1	Energy
2	Mining
3	Agriculture
4	Durable Manufacturing
5	Non-Durable Manufacturing
6	Services

Table 2 presents all regions in the model. We aggregate all countries into eighteen regions with a detailed disaggregation of Asia.

Table 2 Model Regions

Region Codes	**Regions**
USA	United States
JPN	Japan
EUW	Western Europe
AUS	Australia
KOR	Korea
OEC	Rest of Advanced Economies (Canada and New Zealand)
CHI	China
IND	India
INO	Indonesia
PHL	Philippines
VNM	Vietnam
THA	Thailand
MYS	Malaysia
OAS	Other Asia (mainly South Asia excluding India)
LAM	Latin America
AFR	Sub-Sahara Africa
MEN	Middle East and North Africa
ROW	Rest of World (mainly Eastern Europe and Central Asia)

The approach to developing a G-Cubed model is outlined in McKibbin and Wilcoxen (1998, 2013). Several key features of the standard G-Cubed model are worth highlighting here.

First, the model completely accounts for stocks and flows of physical and financial assets. For example, budget deficits accumulate into government debt, and current account deficits accumulate into foreign debt. The model imposes an intertemporal budget constraint on all households, firms, government, and countries. Thus, a long-run stock equilibrium obtains through the adjustment of asset prices, such as the interest rate for government fiscal positions or real exchange rates for the balance of payments. However, the adjustment towards the long-run equilibrium of each economy can be slow, occurring over much of a century.

Second, agents in G-Cubed must use money issued by central banks for all transactions. Thus, central banks in the model set short term nominal interest rates to target macroeconomic outcomes (such as inflation, unemployment, exchange rates, etc.) based on Henderson-McKibbin-Taylor monetary rules. These rules approximate actual monetary regimes in each country or region in the model. These monetary rules tie down the long-run inflation rates in each country as well as allowing short term adjustment of policy to smooth fluctuations in the real economy.

Third, nominal wages are sticky and adjust over time based on country-specific labor contracting assumptions. Firms hire labor in each sector up to the points that the marginal product of labor equals the real wage defined in terms of the output price level of that sector. Any excess labor enters the unemployed pool of workers. Unemployment or the presence of excess demand for labor causes the nominal wage to adjust to clear the labor market in the long run. In the short-run unemployment can arise due to structural supply shocks or changes in aggregate demand in the economy.

Fourth, rigidities prevent the economy from moving quickly from one equilibrium to another. These rigidities include nominal stickiness caused by wage rigidities, lack of complete foresight in the formation of expectations, cost of adjustment in investment by firms with physical capital being sector-specific in the short run, monetary and fiscal authorities following particular monetary and fiscal rules. Short term adjustment to economic shocks can be very different from the long-run equilibrium outcomes. The focus on short-run rigidities is important for assessing the impact over the initial decades of demographic change.

Fifth, the model incorporates heterogeneous households and firms. Firms are modelled separately within each sector. There is a mixture of two types of consumers and two types of firms within each sector, within each country: one group bases their decisions on forward-

looking expectations and the other group follows simpler rules of thumb which are optimal in the long run, but not necessarily in the short run.

(b) Adding Demographics

We introduce demographics into our model following the approach of Blanchard (1985). The approach assumes all households regardless of their ages, are faced with a constant probability of death p. When households make decisions on their lifetime consumption profile, they must take into account the uncertainty of their life spans and thus discount their planned future consumption by the probability of death. Households are assumed to insure against the risk of death in a competitive insurance market such that they receive a rate p of their wealth each period if they survive but leave all wealth to the insurance company if they die. This arrangement changes households' budget constraint by adding a rate p of return on the return from their holdings of financial wealth.

In addition to the probability of death, we further introduce age-dependent productivity for households based on their age-earnings profile following the approach of Faruqee (2002). The idea is that household age-earnings profile follows a function of combined exponential terms as:

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

where $l(s,t)$ denotes the productivity at time t for households born at time s, μ is the labor-augmenting technological progress determined by the above catchup model, a_1, a_2, a_3 and $\alpha_1, \alpha_2, \alpha_3$ are parameters. We use the parameter values for Japan from Faruqee (2002), and then truncate the productivity profile at age 65 assuming households retire at age 65. Figure 2 presents the productivity profile with $\mu = 0$. Due to lack of age-earnings data, we assume the same age-earning profile for all countries in this paper.

We then calculate aggregate labor productivity over time for each region as follows:

$$L(t) = \int_0^t l(s,t)ds = e^{\mu t}\int_0^t \left[a_1 e^{-\alpha_1(t-s)} + a_2 e^{-\alpha_2(t-s)} + a_3 e^{-\alpha_3(t-s)}\right] ds$$

where the second equality holds as we assume that labor-augmenting technological progress is independent of life-cycle productivity. Our calculation proceeds as follows: (1) Borrow individual age-earnings profile parameters for Japan and apply the set of parameter values to all regions in the model; (2) Aggregate individual productivity over all cohorts based on the United Nations population projections (the integral term, referred to as total effective labor

supply); (3) Produce sector-wise labor-augmenting technological progress (referred to as sectoral productivity) over time based on a catchup model, as illustrated in Section 4.1; (4) Combine total effective labor supply with sectoral productivity.

4. Simulation Results

4.1 Baseline scenario

There can be many different demographic change scenarios depending on assumptions about future growth and demographic change. We start by choosing a scenario (the baseline scenario) against which we can compare the alternatives. We choose a simple and intuitive baseline by assuming that population sizes and structures do not change from 2015 onwards.

We first solve the model from 2016 to 2100 with 2015 as the base year. The key inputs into the baseline are the initial dynamics from 2015 to 2016 and subsequent projections from 2016 onwards for sectoral productivity (or technological) growth rates by sector and by country. The sectoral productivity projections follow the approach of Barro (1991, 2015). Over long periods, Barro estimates that the average catchup rate of individual countries to the worldwide productivity frontier is 2% per year. We use the Groningen Growth and Development database (2018) to estimate the initial productivity level in each sector of each region in the model, and then take the ratio of the initial productivity to the equivalent sector in the United States, which we assume is the frontier. Given this initial gap in sectoral productivity, we use the Barro catchup model to generate long-term projections of the productivity growth rate of each sector within each country. Where we expect that regions will catch up more quickly to the frontier due to economic reforms (e.g., China) or more slowly to the frontier due to institutional rigidities (e.g., Russia), we vary the catchup rate over time. The calibration of the catchup rate attempts to replicate recent growth experiences of each country and region in the model. The sectoral productivity growth is the exogenous drivers of sector growth for each country. The growth in the capital stock in each sector of each region is determined endogenously within the model.

Based on these assumptions, we produce a baseline for all economies. Figure 3 presents GDP in 2015 and 2050 for all economies in the baseline. There are significant changes in the world economy from 2015 to 2050 in both absolute and relative terms. These changes in the baseline are independent of demographic change as we freeze demographics from 2015 onwards. The changes are driven by sectoral productivity growth over time and endogenous capital accumulation. As the technology frontier of the world, the US productivity is assumed to grow

at a constant rate into the future, and other economies close their gaps at the sector level with the United States sector by sector based on the catchup model. As emerging economies have low initial technology levels relative to the United States, they enjoy fast technological progress and hence fast economic growth. This productivity catchup alone will significantly change the landscape of the world economy this century. Section 4.2 will show that, in addition to this productivity catchup, asymmetric demographic change across countries will also generate significant differences in growth. In particular, the economy-wide labor productivity is still increasing quickly in emerging Asia and Africa, which will further fuel their future economic growth.

4.2 Global demographic scenarios

The baseline assumes that the population sizes and structures remain unchanged from 2015 into the future. In the alternative demographic scenarios, we use the UN population projections to calculate the total effective labor supply in the future relative to 2015 based on the Blanchard-Faruqee approach outlined above. The changes in the size and structure of the workforce both have productivity implications. We then simulate this productivity change due to the change in workforce structures and sizes as a global demographic shock. Figure 4 presents total effective labor supply for all regions from 2015 to 2050 where the productivity in 2015 is normalized to one. To make the presentation more informative, we organize the regions into five groups: (1) Ageing developed economies (ADE): JPN, EUW, KOR; (2) Growing developed economies: USA, AUS, OEC; (3) Emerging Asian economies (EAE) (Southeast and South Asia): VNM, OAS, PHL, MYS, IND, INO, THA; (4) Growing Africa and the Middle East: AFR, MEN; (5) Other regions: CHI, LAM, ROW. To understand the regional contributions to the global adjustment, we then simulate each shock individually for six regions: ADE, EAE, USA, CHI, LAM, AFR and MEN combined. We do not run the shock for ROW separately because its demographic change is quite small.

The productivity in ageing developed economies will decline substantially, particularly in Japan and Korea. Japan's productivity declines by 14% by 2030 and by 33% by 2050. Europe's situation is better, with a declining rate of 5.5% by 2030 and 14% by 2050. Other developed economies still have increasing effective labor supply due to their migration policies. Australia has a high growth rate of 10% by 2030 and 24% by 2050, followed by New Zealand and Canada. The United States has mild growth in productivity by 5% by 2030 and by 10% by 2050. Most emerging and developing countries have strong growth in productivity. Most countries in South Asia and Southeast Asia are relatively young except China, Thailand, and Vietnam. In

particular, China's productivity declines by 7% by 2030 and by 22% by 2050. Africa and the Middle East will enjoy significant demographic dividends. Africa's productivity increases by more than 50% by 2030 and by about 150% by 2050. Latin America has moderate growth until 2040 before declining. Eastern Europe and Central Asia (ROW) have slight declines over time.

While the elderly dependency ratio is a common indicator to measure the extent of population ageing, the change in the effective labor supply due to the change in population structures also have important production consequences. Even if the elderly dependency ratio is increasing, the change in the effective labor supply can also be increasing because when young workers move into their middle-age stage, their productivity increases by 2-3 times. This second effect can offset the productivity loss of retirees and results in even higher effective labor supply. For example, the elderly dependency ratio in the United States, Australia, and the rest of the OECD countries are all expected to increase this century. However, their effective labor supply due to the changing population structure continues to increase over the entire century. Most emerging Asian economies (except Thailand and Vietnam) also have increasing effective labor supply despite having increasing elderly dependency ratios.

Our life-cycle modeling approach captures only the direct effect of demographic change on the production side in each economy, but not the effect of demographic change on consumption patterns. The shift in consumption patterns is to be incorporated into future research.

As there are eighteen regions in the model, we focus on the results for major regions, including the United States, Japan, Europe, China, Africa, and India, where India is a representative economy in emerging Asia. To make the analysis informative, we focus on three shocks in ageing developed economies, emerging Asian economies and the entire world, respectively. We take the two regional shocks as examples to illustrate the mechanisms in our model in detail, and then show the quantitative results of other regional shocks in the global shock. It is important to stress that the results are presented as percentage changes relative to what would have been the case in a particular year rather than the changes relative to the initial year. We focus on the results over the period of 2016-2050 for some key macroeconomic variables including GDP, investment, consumption, the interest rate, the exchange rate, trade balance, per capita GDP and per capita consumption all in real terms.

(a) Demographic shock in ageing developed economies

As the labor force is ageing and shrinking in ageing developed economies, changes in population structures imply that their effective labor supply is also declining. As a result, these

economies have excessive capital which leads to a decline in investment (Figure 5a). Investment in Europe declines by 33% by 2030 and 50% by 2050, relative to what it otherwise would have been. Investment in Japan declines much more substantially by 56% by 2030 and 84% by 2050. As capital flows away from Europe and Japan, the rest of the world benefits from absorbing capital. The United States has the largest increase in investment at about 4% in the short run. Most other regions also absorb capital, but investment increases to a lesser extent in the short run. Australia reduces investment because its external demand significantly decreases from its major trading importers Japan, Europe and Korea.

The investment reduction has significant negative impacts on economic growth in the ageing economies (Figure 5b). GDP in Japan declines relative to the baseline, by 17% by 2030, and by 36% by 2050. GDP in Europe is 7% lower by 2030 and 16% by 2050. Per capita GDP in Europe declines with a similar rate by 2050, given the European population is quite similar in 2050 to 2015 (Figure 5c). However, per capita GDP in Japan declines much less than its GDP reduction because its population shrinks by 17% by 2050. The spillover effects of this demographic shock on GDP in most other regions are slightly positive with growth rates less than 0.3% in the short and medium run but turn to slightly negative with growth rates above -0.6% by 2050.

Due to the labor shrinkage in the ageing economies, the marginal product of capital falls in these economies, reducing the real interest rate (Figure 5d). In Japan, the real interest rate declines by 82 basis points by 2030 and by 113 basis points by 2050. In Europe, the real interest rate declines by 59 basis points by 2030 and by 63 basis points by 2050. As capital flows out of these economies, there is additional capital in other regions, which lowers the real interest rate in the medium and long run. Taking the global economy as a whole, when total labor shrinks, total capital is excessive, and the real interest rate must fall on average. This demographic shock has significant impacts on the real interest rate in the world capital markets, given the large economic sizes of Japan and Europe. In other major economies, the real interest rate decreases by about 20 basis points by 2030 and by about 40 basis points by 2050.

However, the real interest rate in China and Africa increases in the short run because the Central Banks in these economies target the nominal exchange rate. When capital flows into the rest of the world, the US dollar appreciates more than the Chinese Yuan, resulting in a depreciation of the Chinese currency relative to the US dollar. The Chinese Central Bank tightens its monetary policy by increasing the nominal interest rate to achieve its exchange rate target. On

the other hand, the inflation rate decreases because capital flows in and output expands. The two effects push up the Chinese real interest rate in the short run.

There are wide wedges in the real interest rate between ageing economies and other economies, and also between Japan and Europe. The wedges across regions are driven by the real exchange rate divergences (Figure 5f) according to the real interest rate parity.

The reduction in the real interest rate drives capital outflows. Capital outflows depreciate currencies in Japan and Europe, which drives up exports and drives down imports leading to trade surpluses (Figure 5e). Trade balances increase by 0.8% of GDP in Europe and by 4% of GDP in Japan in the short run, and their surpluses last for several decades. Capital flows appreciate foreign currencies, which drives imports up and exports down, leading to trade deficits. The quantitative impacts are less than 1% of GDP for all other economies.

As the nominal exchange rate depreciates, the real exchange rate also depreciates immediately (Figure 5f). The real exchange rate depreciates by 1% in Europe and by 5% in Japan in the short run. However, in the medium- and long-run, as production falls significantly in Europe and Japan, their goods become more expensive relative to the goods in other economies without productivity change in this scenario, which pushes up the real exchange rates in the two countries. In other economies, as the nominal exchange rate appreciates, the real exchange rate also appreciates immediately. However, in the medium- and long-run, as production rises significantly in other economies, their goods become cheaper relative to the goods in shock economies with productivity reductions, which pushes down the real exchange rates in the other regions.

Real wages decline as capital flows out, and investment falls (Figure 5g). The real wage declines by 4.8% by 2030 and by 13% by 2050 in Europe. The decline is much more significant in Japan, with a reduction of 12% by 2030 and 28% by 2050. This decline in real wages is in contrast with the case of a closed economy where population ageing reduces labor force and increases capital per worker and hence real wages. In other economies, the real wage slightly increases as capital flows in and investment rises.

As the real wage significantly declines in the ageing economies, human wealth (the present value of lifetime labor income) declines substantially. However, the decrease in the real interest rate has an offsetting effect through discounting. The reduction in human wealth pushes down consumption of forward-looking households whose consumption depends on human wealth (and financial wealth). However, the change in consumption of backward-looking households

is different. As firms significantly reduce investment in response to the labor shock, the profit (net investment) increases in the short run, resulting in higher after-tax income of households temporarily. Backward-looking households consume all their income and their consumption increases in the short run. Since backward-looking households dominate forward-looking households, aggregate consumption increases in the short run (Figure 5h). In the medium- and long run, the net profit gradually decreases, and hence after-tax income also decreases. Both forward-looking and backward-looking households reduce their consumption in the long run, resulting in lower aggregate consumption. However, the change in per capita consumption is quite different from that in aggregate consumption (Figure 5i). Per capita consumption continuously declines in Europe, and continuously increases in Japan because the Japanese total population declines more quickly.

In other economies, as the real wage increases and the real interest rate declines, human wealth increase and total wealth also increase although financial wealth slightly decreases. The increase in total wealth pushes up the consumption of forward-looking households. In contrast, the slight decline in financial wealth and hence in after-tax income slightly reduces consumption of backward-looking households. But the former change dominates the latter, resulting in higher aggregate consumption. The change in per capita consumption is the same as that in aggregate consumption in each other economy because we assume unchanged population structures in other economies.

The quantitative impact on consumption is much smaller than the change on the production side. While domestic investment decreases, households move financial capital to other regions and hold more foreign assets for higher marginal product of capital, preventing significant contraction in financial wealth. Put differently, demographic-driven current account improvements partially offset the reduction in rates of return on capital that would otherwise occur in Japan and Europe. Total wealth does not decrease proportionally as human wealth, so consumption is not significantly affected. Therefore, international capital flows provide a mechanism to share demographic shocks across countries to avoid an otherwise sharp contraction in consumption.

Consumption in other regions benefit from international capital flows driven by population ageing in Japan and Europe. International capital flows generate Pareto-improving outcomes for all regions when facing demographic shocks compares to an autarky situation. This is consistent with the traditional wisdom that financial globalization is desirable for development and growth. But there is a caveat. Our simulation does not consider possible risk changes

associated with persistent current account imbalances driven by long-term demographic transitions.

(b) Demographic shock in emerging Asian economies

The discussion of the case where the demographic shock only occurs in emerging Asian economies will focus on India as a representative country (given India is the largest economy in emerging Asia and its demographic pattern is quite similar to other emerging Asian economies). India is still young demographically, and its total effective labor supply is estimated to increase by 27% by 2050. Due to the productivity increase, investment increases significantly by nearly 30% and stays stable until 2050 (Figure 6a). India's GDP increases steadily by 23% until 2050, when its total effective labor supply starts to decline (Figure 6b). The real interest rate increases substantially by above 200 basis points over 2020-2030 (Figure 6d). Capital flows into India, and the Indian currency appreciates, resulting in trade deficits by more than 4% of GDP in the short run (Figure 6e). The real exchange rate initially appreciates by 5% and then decline quickly to be 30% lower by 2050 (Figure 6f). This real exchange rate pattern is due to India's rapid economic growth, which reduces the relative price of Indian goods. While Indian GDP increases steadily, per capita GDP increases by 2% by 2030 and then gradually decline below the baseline (Figure 6c). Per capita GDP slightly increases by 2030 because Indian workers become more productive on average due to life-cycle patterns, but does not increase as much as GDP because the total effective labor supply increase is mainly driven by the increase of workers. When the economies become old and the total effective labor supply slows down, per capita GDP declines quickly when older workers retire. The example of India indicates that emerging economies can significantly benefit from their demographic dividends in terms of economic growth, but this does not necessarily improve their per capita GDP. Workers significantly benefit from capital inflows because a higher capital stock increases the marginal product of labor. The real wage increases by about 25% by 2030 (Figure 6g). India's consumption does not change much in the short run but steadily increases in the medium and long run (Figure 6h). As the real wage rises, human wealth increases although the real interest rate increase has an offsetting effect, which will increase the consumption of forward-looking households. However, as firms significantly increase investment, the profit (net investment) decreases in the short run, resulting in lower after-tax income of households temporarily. Reduced income will decrease the consumption of backward-looking households and thus offset the positive impact of forward-looking households on consumption in the short run. In the long run, after-tax income will also increase, so all households will enjoy higher

consumption, resulting in higher aggregate consumption. In contrast, per capita consumption decreases because India's elderly dependency ratio will also increase, although the effective labor supply rises (Figure 6i).

Most other economies benefit from the demographic shock in emerging Asia in the medium and long run. Still, the impacts are relatively small, with economic growth rates of less than 0.4% by 2030 and less than 0.7% by 2050. The real interest rates in other economies all increase in the medium and long run, with 10-25 basis points by 2030.

(c) Global demographic shock

Combing all regional shocks creates a global shock. In general, if one region is experiencing decreasing effective labor supply due to demographic change, the impacts in this economy have similar patterns as the impacts in Europe and Japan. For example, China's effective labor supply decreases substantially (less than Japan but more than Europe), so the impacts in China are also significant (less than Japan but more than Europe). China's demographic dividend, which has significantly contributed to its long-term economic growth, disappears. Due to China's rapid ageing, Chinese per capita GDP declines quickly.

On the other hand, if one region is experiencing increasing effective labor supply, the impacts in this economy have similar patterns as the impacts in emerging Asian economies. For example, compared to emerging Asia's demographic shock, Africa's shock produces qualitatively similar but much larger impacts, given its demographic structure is very young. Our results suggest that emerging Asia and Africa both have great potential for future economic growth if they can absorb significant foreign capital. Absorbing foreign capital is beneficial not only for those developing countries but also for those ageing developed countries, creating Pareto-improving outcomes for the world economy compared to the autarky situation. Furthermore, when capital continues to flow into developing countries, they will accumulate large external debts, which will increase financial risks. Many economic and financial crises are attributable to long-term external deficits. In this sense, those developing countries must improve their financial institutions to increase the benefits of capital flows and capital allocation into productive uses, while minimizing the risks.

The rest of this section presents the global results in two parts. The first part shows the changes in macroeconomic variables relative to their baseline levels due to the global demographic shock, and the second part shows the changes in those variables relative to their initial levels in 2015.

The results vary across regions due to the asymmetric nature of the demographic shocks. Underlying the GDP outcomes are changes in labor supply as well as changes in the sectoral capital stocks in different economies driven by different investment responses (Figure 7a). Investment in Africa increases by 74% by 2030 and by 130% by 2050. In the Middle East, investment increases by about 40% over 2030-2050. Emerging Asian economies also have strong investment growth, with rates above 30% over 2030-2050 in India, 50-55% in other South Asian economies, 30-35% in Philipines, 20% in Malaysia, and about 30% in Indonesia. Among developed countries, the United States, Canada, Australia and New Zealand all experience strong investment driven by their increasing effective labor supply, due to their immigration policy. Investment increases by 20-25% over 2030-2050 in the United States, by 25-40% in Canada and New Zealand, and by 30-50% in Australia. In contrast, ageing developed countries will experience significant contraction in investment. European investment decreases by 30% by 2030 and by 47% by 2050. Korea has smaller reductions, with 21% by 2030 and 41% by 2050. Japan's investment decreases more substantially, by 50% by 2030 and by 80% by 2050.

Due to the impacts on investment, GDP in Africa increases by 55% by 2050, followed by other young developing economies such as South Asia, the Middle East, Latin America, Southeast Asia with growth rates between 15-35% by 2050 (Figure 7b). Among developed economies, the United States has a mild growth rate of 8.5%, and Canada, Australia and New Zealand have stronger growth rates between 15-25%. Japan has a substantial contraction by 35% by 2050, followed by Korea and Europe with a reduction of 24% and 15% respectively. Although young economies benefit from increasing effective labor supply in terms of economic growth, per capita GDP decreases in all economies due to the increase in the elderly dependency ratio.

The impacts on GDP will significantly change the landscape of the world economy. Table 3 present the GDP share of each region in the world in 2050 in the baseline and the global demographic scenario respectively as well as in the initial period of 2015. In the baseline, the GDP shares of developed regions in the world economy will decline from 54% in 2015 to 42% in 2050, while the shares of developing regions will increase from 46% to 58% over the period, due to the productivity catchup in developing regions. The severe population ageing in Japan and Europe will further reduce their GDP shares. For example, Japan's GDP share is 5.2% in 2015, and will remain at 5.4% by 2050 in the baseline, but will reduce to 3.4% due to the ageing process. The United States and other developed countries are not significantly affected by demographic change given their changes are small except Korea.

In contrast, emerging Asia, Africa and Latin America will have strong economic growth in the baseline, which will be further advanced by their demographic change. The GDP share of Emerging Asia will nearly double from 7.0% in 2015 to 11.3% in 2050 in the baseline and will increase by another 2.0% due to its demographic process. Africa's growth is even more significant, with a share of 4.2% attributable to its demographic change.

Table 3 Change in GDP shares of the global economy (%)

Region	Baseline 2015	Baseline 2050	Global Demographic Scenario 2050	Shock Impact By 2050
USA	22.5	16.0	16.7	0.7
JPN	5.2	5.4	3.4	-2.0
EUW	20.5	16.1	13.2	-3.0
ODE	5.5	4.7	4.5	-0.2
CHI	13.7	18.9	15.3	-3.6
EAE	7.0	11.3	13.3	2.0
LAM	6.3	8.7	10.0	1.4
AFR	4.2	5.1	9.3	4.2
MEN	4.1	5.2	6.3	1.1
ROW	10.9	8.6	7.9	-0.6

The responses of the real interest rate to demographic change are also divergent across regions (Figure 7f). Given the levels of country risk, the differences between real interest rates reflect the expected changes in real exchange rates over time. The real interest rate increases by nearly 500 basis points in Africa by 2030. South Asia, most of Southeast Asia, Middle East, Latin America all have strong increases in the real interest rate with about 150basis points, followed by the United States, Canada, Australia and New Zealand with 70-120 basis points upwards. Several recent studies show that demographic change has contributed to the declining real interest rate in developed economies in the last several decades (Carvalho et al. 2016; Gagnon et al. 2016; Fujita and Fujiwara 2016; Lisack et al. 2017; Sudo and Takizuka 2018). A decline in real interest rates is consistent with the results of our first shock in ageing developed economies. However, if we take Africa and emerging Asia into our analysis, their young labor force will potentially fuel their economic growth, attracting capital flows from ageing economies and pushing up the world real interest rate. In the first shock of ageing developed economies, Japan's real interest rate declines by above 110 basis points by 2050. The decline in real interest rates is significantly offset in the case of the global shock, with a reduction of 80 basis points. Europe's real interest rate declines by 59 basis points by 2030 and by 63 basis

points by 2050 due to its demographic shock, but increases by 13 basis points by 2030 and decreases only by 30 basis points by 2050 in the global shock.

The relative change in production and output across countries shifts the real exchange rate dramatically in the long run (Figure 7f). The real exchange rate declines by more than 70% by 2050 in Africa, and by about 30% in South Asia, followed by Latin America and the Middle East by nearly 20%. On the other hand, the rate increases by 30-35% by 2050 in Japan, Korea and China, and increases by 20% in Europe. The US real exchange rate does not change much given its modest demographic change. This shift in the real exchange rate drives the divergence in the real interest rate across countries according to the real interest rate parity.

The trade balance will improve in the regions with increasing effective labor supply while worsening in the regions with decreasing effective labor supply (Figure 7e). Japan's trade balance improves by 4.5% of GDP in the short run and then gradually return to the baseline. China will run a trade surplus of 1-3% of GDP in the first two decades, and Europe will run a trade surplus of 1-2% of GDP in the first decade. India and Africa will experience large trade deficits, with 4% of GDP in India and 15% of GDP in Africa in the short run. Compared to regional shocks, for example, the first shock in the ageing developed economies, the global demographic effect on international trade is notable. In the regional demographic shock, Japan's trade balance improves by 3.7% of GDP but improves by 4.5% of GDP in the global shock. The improvement in the Japanese current account occurs because emerging Asia and Africa have large productivity growth and attract further capital flows from Japan.

Capital flows significantly benefit workers in young economies because more capital implies a rise in the marginal product of labor. Those workers would otherwise be worse off in a closed economy. The real wage will increase by 54% by 2030 and by 258% by 2050 in Africa and will increase by 30% by 2030 and by 83% by 2050 in India (Figure 7g). Workers in Japan, Europe and China will be harmed with declining real wages, with a reduction rate of 25%, 11% and 26% by 2050 respectively. Labor is generally difficult to move across countries. However, capital flows across borders provide a mechanism to reallocate production resources at the global level from less productive to more productive economies, resulting in higher global welfare.

It was argued above that consumption changes by less than production responds to demographic shocks in an open economy context because households are smoothing consumption. Consumption changes by less than 10% by 2030 and by less than 20% by 2050 in all regions except Africa (Figure 7h). The smaller change in consumption relative to the

change in production demonstrates that trade and financial openness provides an avenue to share demographic shocks across countries.

We are not only interested in the changes of variables in the ageing scenario relative to their baseline levels, but also the changes of variables relative to their initial levels in 2015 because these changes will show how the world changes relative to today. Table 4 presents the changes of variables in the face of global demographic change in 2030 and 2050 relative to their 2015 levels. The relative changes consist of two parts: the changes over time relative to the 2015 level in the baseline and the changes at the same time point in the demographic scenario relative to the baseline. The change in the baseline is mainly driven by the productivity growth generated in the catchup model, and then by global demographic change.

Table 4 Change of macroeconomic variables relative to 2015

Variables	Year	USA	JPN	EUW	CHI	IND	AFR
Investment (%)	2030	57.1	27.8	9.6	135.5	314.0	247.4
	2050	155.6	-12.0	34.1	237.3	610.6	645.8
GDP (%)	2030	28.9	34.2	22.2	82.8	186.5	138.8
	2050	84.6	61.5	60.1	179.0	454.6	453.6
Per Capita GDP (%)	2030	18.3	42.2	19.3	75.6	149.6	64.0
	2050	56.2	95.3	58.3	179.9	343.2	152.9
Real Interest Rate (Percentage Point)	2030	3.7	3.8	3.5	5.2	3.5	12.0
	2050	2.9	3.3	2.8	3.5	-0.4	9.6
Trade Balance (% GDP)	2030	-3.3	-0.3	-2.2	-3.2	5.1	1.9
	2050	-7.2	-2.8	-6.4	-3.8	4.4	8.1
Real Exchange Rate (%)	2030	24.4	26.5	25.1	-2.9	-48.5	-42.8
	2050	21.0	24.7	26.7	4.6	-31.8	-67.8
Real Wage (%)	2030	11.8	1.3	5.0	43.2	91.2	126.4
	2050	15.0	3.1	7.4	54.2	231.8	269.3
Consumption (%)	2030	29.9	41.4	30.3	72.5	148.0	86.3
	2050	92.9	91.6	84.9	199.3	449.8	294.5
Per Capita Consumption (%)	2030	19.2	49.8	27.2	65.7	116.1	28.0
	2050	63.2	131.8	82.8	200.3	339.5	80.2

We have shown that the productivity catchup and the demographic transition will significantly transform the landscape of the world economy by 2050 relative to 2015. The United States is assumed to be at the productivity frontier and have constant productivity growth. Productivity growth is the main driver of future US GDP growth given its demographic change is mild. Japan also has similar productivity growth to the United States because it largest sectors are close to the productivity frontier. However, due to its severe ageing process, Japanese GDP does not change much by 2050, indicating that the impact of productivity growth is completely

offset by demographic change. Europe has weaker economic growth than the United States given its ageing process. Developing regions including China, emerging Asia and Africa are expected to benefit from productivity catchup to the United States significantly.

Meanwhile, emerging Asia and Africa also reap substantial demographic dividends. The two impacts combined, result in fast economic growth in India and Africa, with their GDP six times larger than the 2015 levels by 2050. However, China's economic growth will be offset by its rapid ageing. Interestingly its productivity catchup effect is expected to dominate the ageing effect, leading to a doubling of Chinese GDP by 2050.

While demographic transitions significantly contribute to economic growth in developing regions, they do not improve per capita GDP, which is a common measure of living standards. The improvement in per capita GDP relies on labor-augmenting technological progress. But this demographic comparative advantage in developing countries can attract capital flows from the world market. Developing countries should take this opportunity to use additional capital not only for production but also for research and development and for investment in education to improve individual labor productivity.

The real interest rate increases over time in all regions. The rise in the real interest rates is mainly driven by the productivity growth in the baseline in the United States, Japan, Europe and China. In addition to the productivity growth, demographic change also contributes to the real interest rate increases in India and Africa, as shown in the global demographic shock.

The two factors also drive changes in real wages. The productivity growth in the baseline increases the marginal product of labor and has a positive effect on real wages. Demographic transitions drive capital flows across countries and change capital stock, which also affects the marginal product of labor. The increase in real wages in the United States is mainly driven by the productivity growth given its mild demographic change. The decrease in real wages in Japan is the outcome of capital outflows dominating productivity growth. In India and Africa, the impacts of productivity growth and capital inflows go in the same direction, and the latter impact is much more significant.

As financial capital can move around the world, household income and consumption are less affected than production and output in ageing regions. Consumption in Japan and Europe has similar growth rates to the United States. In India and Africa, the substantial increases in consumption are driven by three main factors: productivity growth, spillover effect, and labor

expansion. Per capita consumption increases much less than aggregate consumption in India and Africa.

5. Conclusions

This paper investigates the global impacts of projected worldwide demographic change in a multi-country multi-sector general equilibrium model. It finds that if there are no impediments, demographic-driven capital flows will flow from more ageing to less ageing and still growing countries will potentially be substantial. This pattern of capital movements is beneficial for young economies to finance productive investment, and also favorable for ageing economies to reap higher rates of return on capital than would be possible in autarky. The paper also suggests that population ageing would reduce the real interest rate in ageing economies. However, this reduction would be substantially offset by the increase in the real interest rate in young economies such as emerging Asia and Africa. Demographic change has significant impacts on their GDP, so the asymmetric demographic change would significantly change the landscape of the world economy, but the spillover impacts on GDP across countries are quite small. In particular, emerging Asia and Africa would enjoy strong economic growth from their significant demographic dividends, but their demographic change does not improve per capita GDP. Also, the results show that capital flows can avoid a significant contraction in consumption that would otherwise occur in ageing countries.

Several extensions of this paper are possible. First, the one stage life in this paper can be extended to two stages - working and retirement - following the approach of Gertler (1999). This extension will allow for additional impacts on consumption of retirees. Second, the two stages of life can be further extended to four stages: childhood, young working period, old working period, and retirement. This extension will allow more dynamics over the working period, and also separate childhood from adulthood. Third, the utility function with a constant income elasticity in the current model can be replaced with a linear expenditure system. A linear expenditure system will allow non-unitary income elasticities and hence allow more structural change from changing consumption patterns in response to demographic shocks. Fourth, an additional sector for health services can be added into the model to capture the impacts of high demand for health services from older generations. Fifth, a pension system can be incorporated to investigate fiscal sustainability.

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Appendix A. G-Cubed Regions

Western Europe:

Germany, United Kingdom, France, Italy, Spain, Netherlands, Belgium, Luxemburg, Ireland, Greece, Austria, Portugal, Finland, Cyprus, Malta, Slovakia, Slovenia, Estonia, Norway, Sweden, Switzerland, Denmark, Iceland, Liechtenstein.

Rest of Advanced Economies:

Canada, New Zealand.

Other Asia:

Hong Kong, Singapore, Laos, Myanmar, Cambodia, Rest of East Asia, Rest of South East Asia, Bangladesh, Nepal, Pakistan, Sri Lanka, Rest of South Asia.

Latin America:

Argentina, Bolivia, Brazil, Chile, Costa Rica, Ecuador, Guatemala, Mexico, Nicaragua, Panama, Peru, Paraguay, Uruguay, El Salvador, Honduras, Venezuela, Caribbean, Rest of South America.

Sub-Sahara Africa:

Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Guinea, Nigeria, Senegal, Togo, Rest of Western Africa, Central Africa, South Central Africa, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Tanzania, Uganda, Zambia, Zimbabwe, Rest of Eastern Africa, Botswana, Namibia, South Africa, Rest of South African Customs Union.

Middle East and North Africa:

Egypt, Algeria, Morocco, Sudan, Tunisia, Libya, Iran, Bahrain, Israel, Jordan, Kuwait, , Oman, Qatar, Saudi Arabia, United Arab Emirates, Yemen, Turkey, Iraq, Lebanon, Palestinian Territory, Syria.

Rest of World:

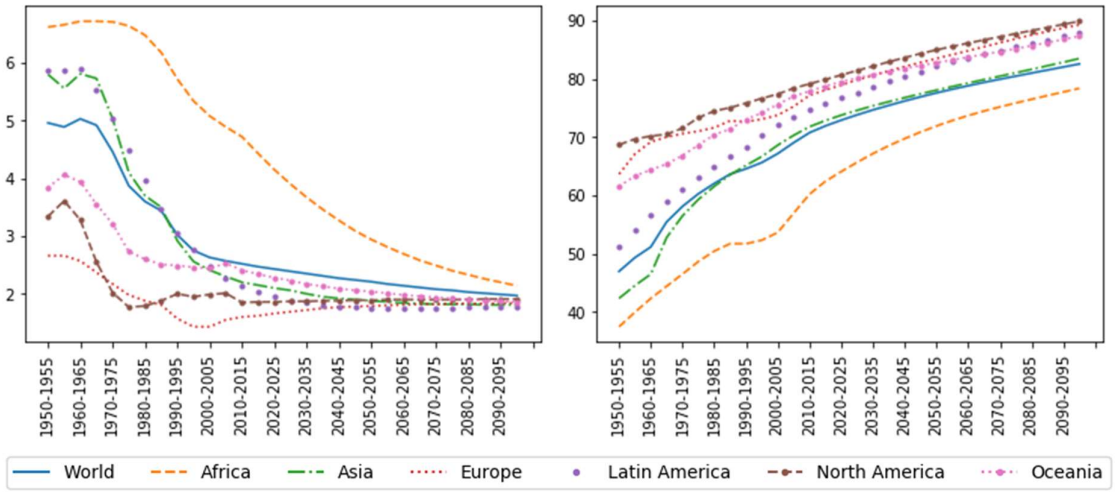
All countries not included in other groups, mainly including Eastern Europe and Central Asia.

Appendix B. Figures

Figure 1 Global Demographic Trends

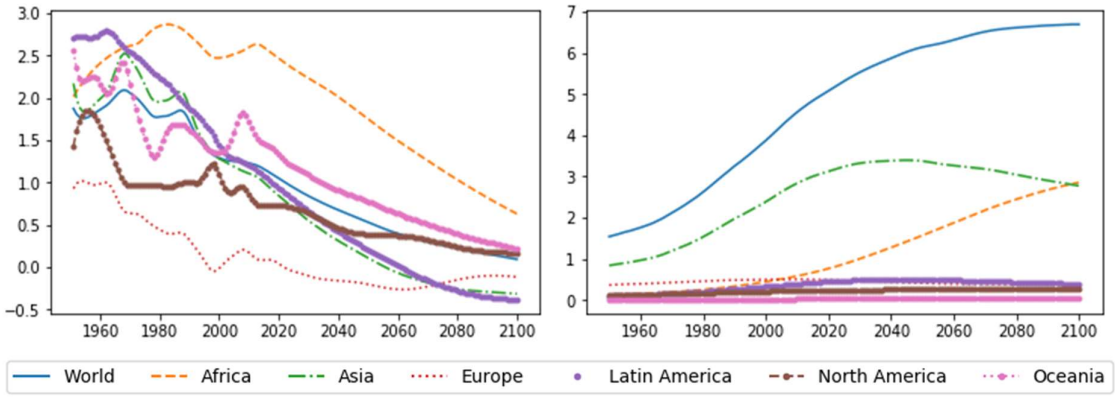
(a) Total Fertility Rates

(b) Life Expectancy



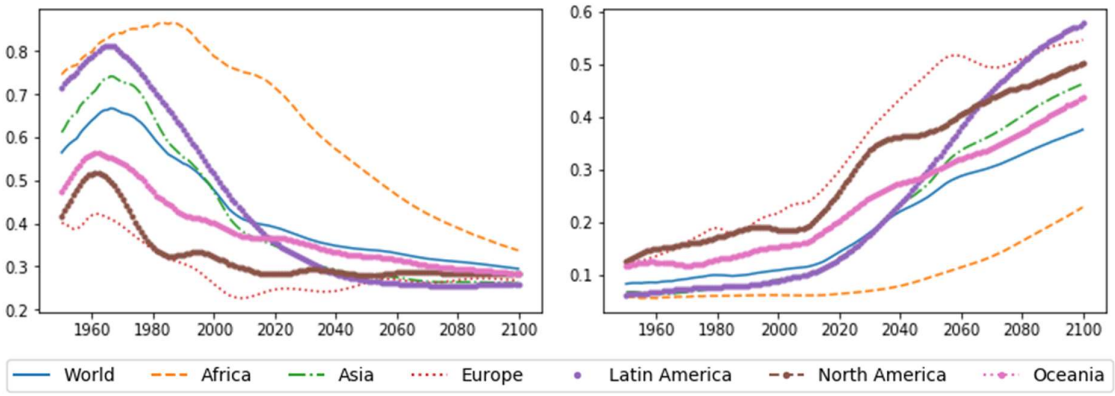
(c) Population Growth Rates

(d) Working-Age Population (Billion)



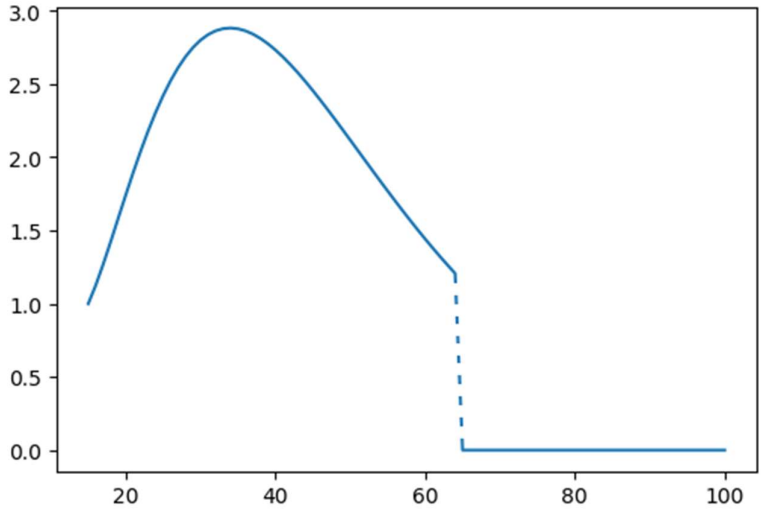
(e) Youth Dependency Ratio

(f) Elderly Dependency Ratio



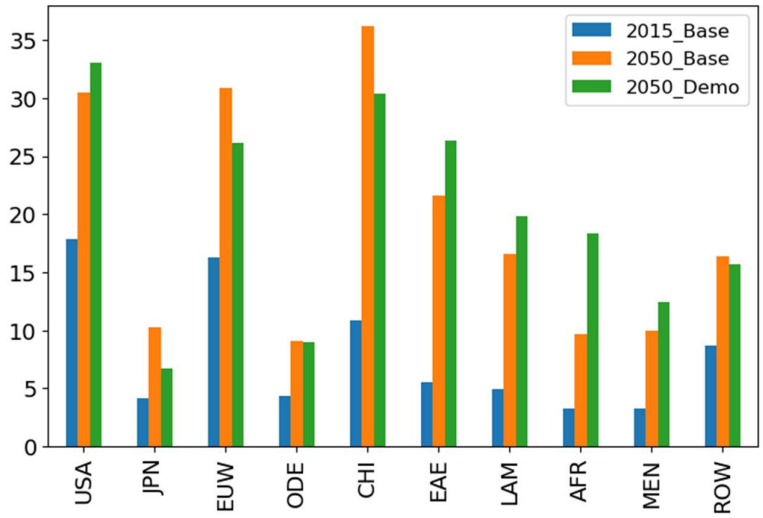
Data Source: The United Nations World Population Prospects: The 2019 Revision.

Figure 2: Individual Life-Cycle Productivity Over Age



Source: Authors' Calculation.

Figure 3: Global GDP: Baseline 2015, Baseline 2050 and Demographic Scenario 2050 (Billion, 2015 US $)

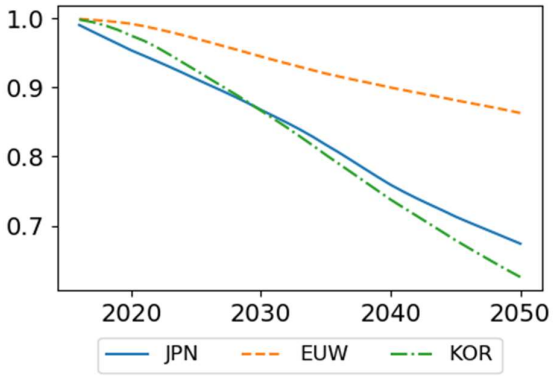


Source: G-Cubed Model GGG6M_v151

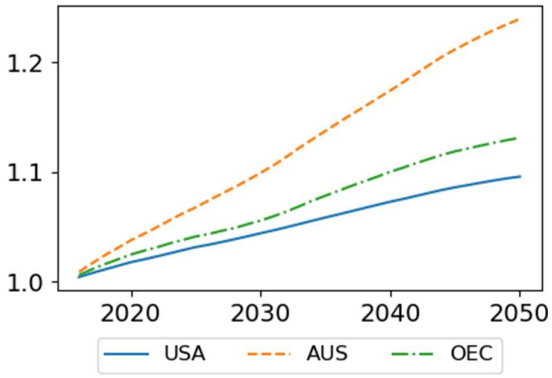
Figure 4: Total Effective Labor Supply

Source: Authors' Calculation.

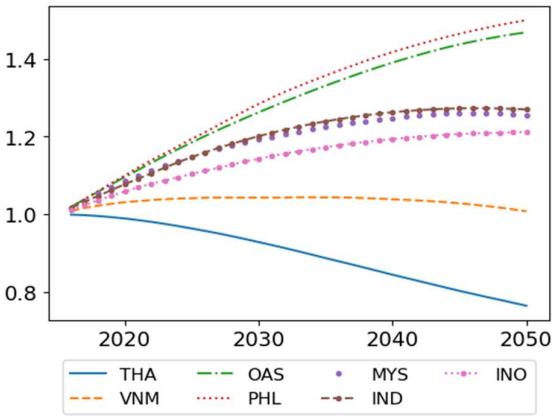
(a) Ageing Developed Economies



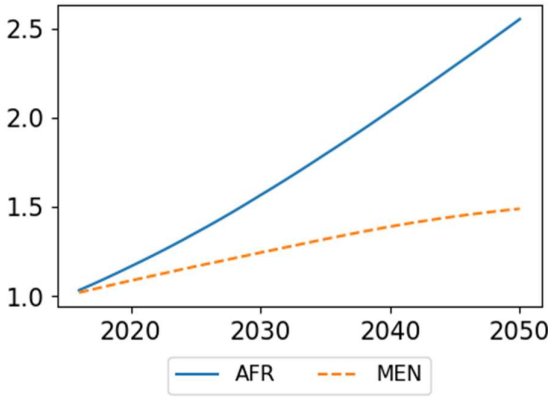
(b) Growing Developed Economies



(c) Emerging Asian Economies



(d) Africa and Middle East



(e) Other Regions

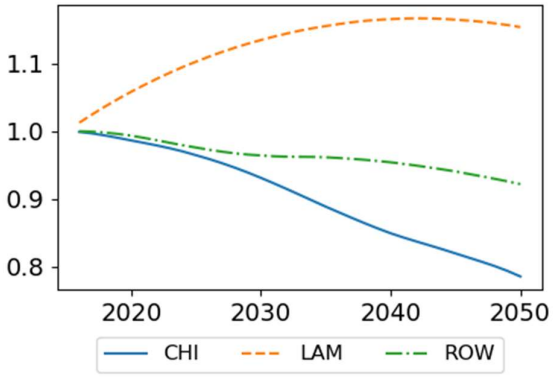
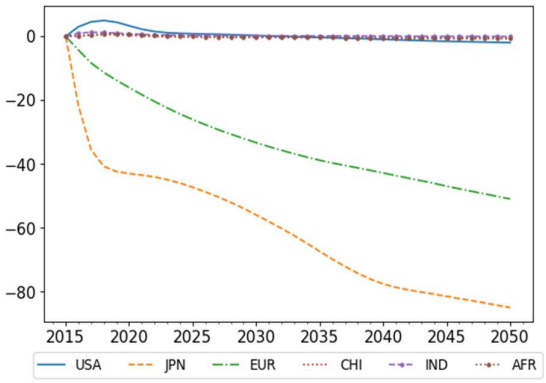


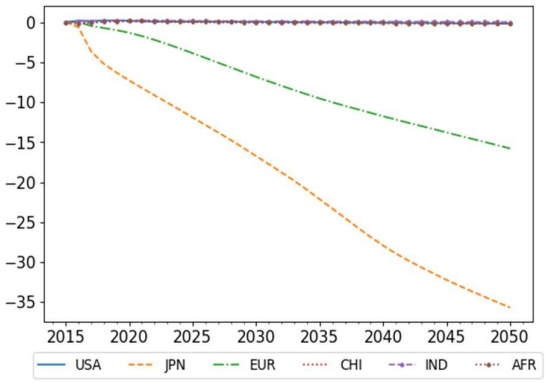
Figure 5 Impacts of Demographic Change in Ageing Developed Economies

Source: G-Cubed Model GGG6M_v151

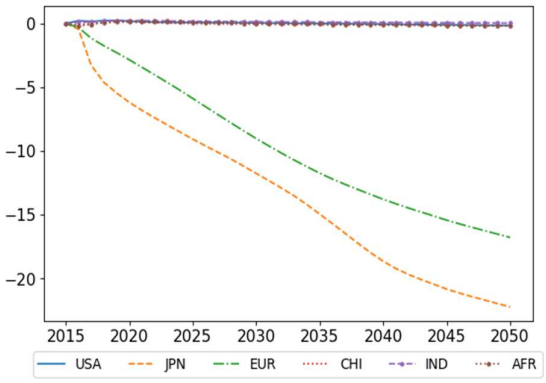
(a) Investment (%)



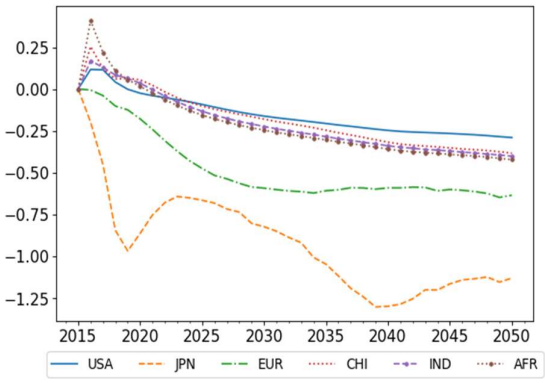
(b) GDP (%)



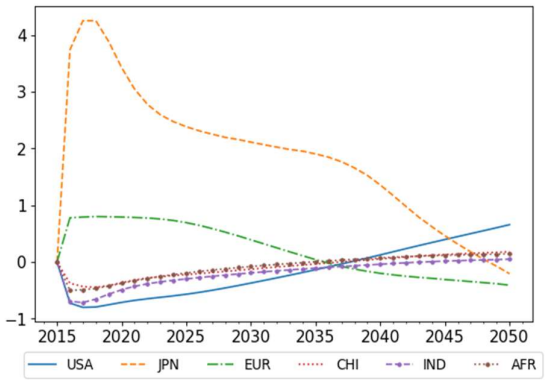
(c) Per Capita GDP (%)



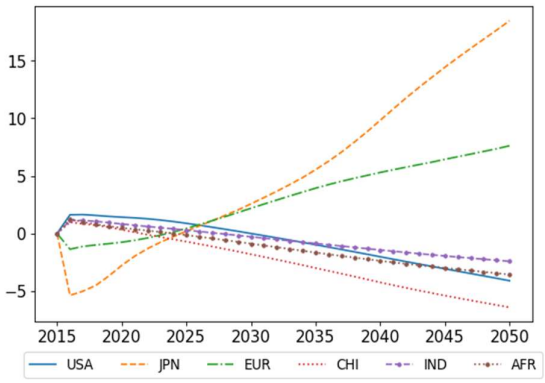
(d) Real Interest Rate (Percentage Point)



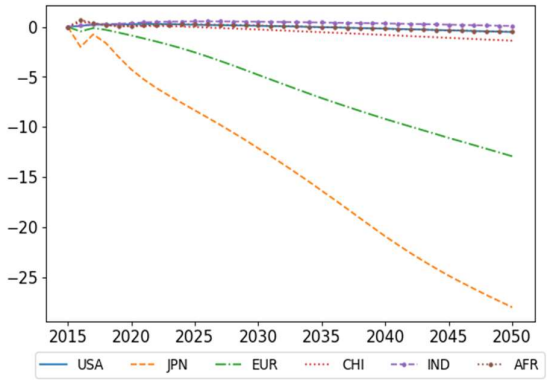
(e) Trade Balance (% of GDP)



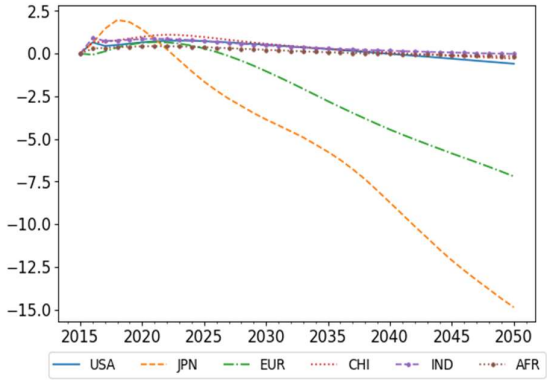
(f) Real Exchange Rate (%)



(g) Real Wage (%)



(h) Consumption (%)



(i) Per Capita Consumption (%)

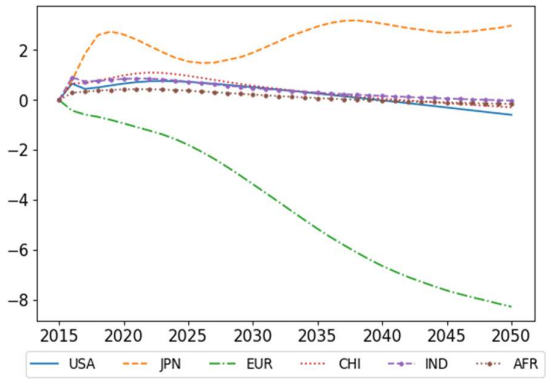
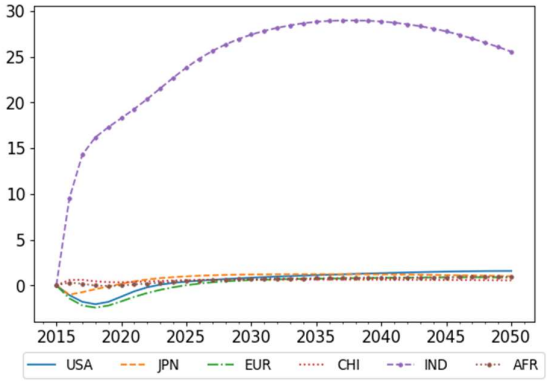


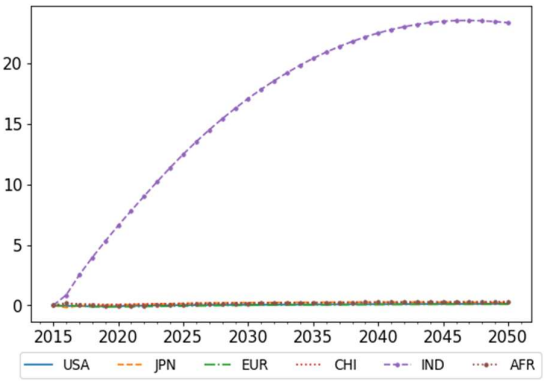
Figure 6 Impacts of Demographic Change in Emerging Asian Economies

Source: G-Cubed Model GGG6M_v151

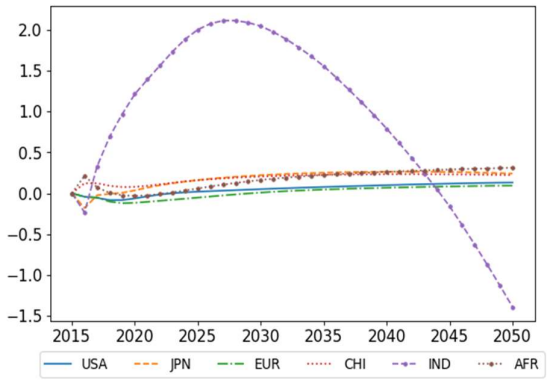
(a) Investment (%)



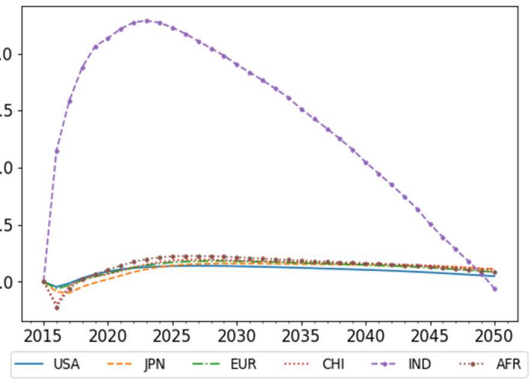
(b) GDP (%)



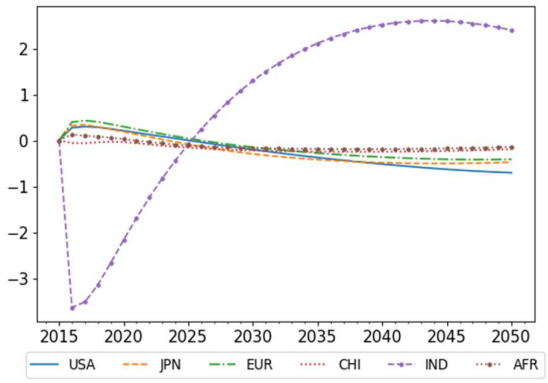
(c) Per Capita GDP (%)



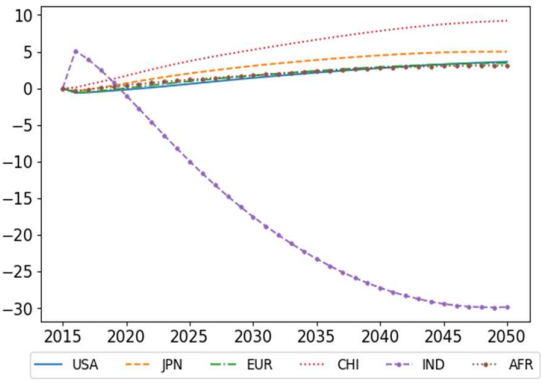
(d) Real Interest Rate (Percentage Point)



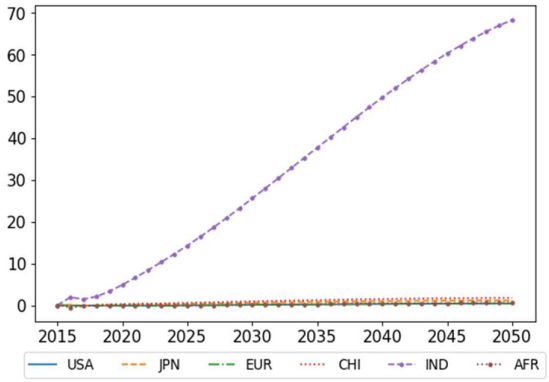
(e) Trade Balance (% of GDP)



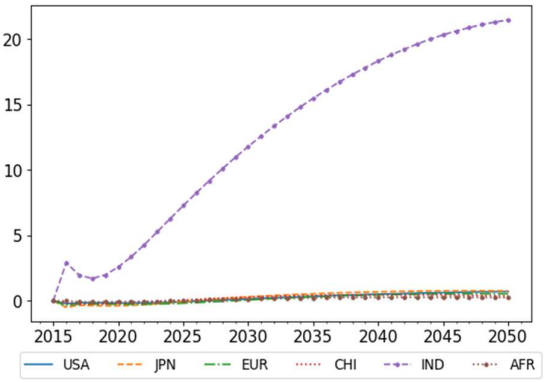
(f) Real Exchange Rate (%)



(g) Real Wage (%)



(h) Consumption (%)



(i) Per Capita Consumption (%)

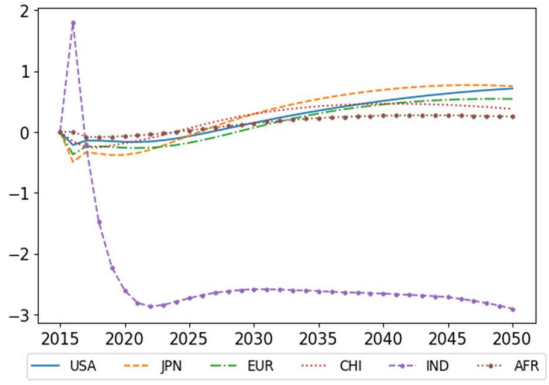
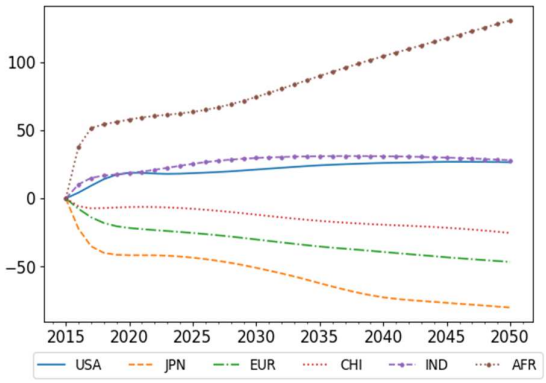


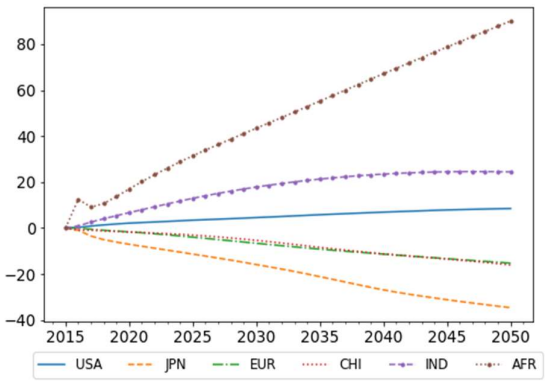
Figure 7 Impacts of Global Demographic Change

Source: G-Cubed Model GGG6M_v151

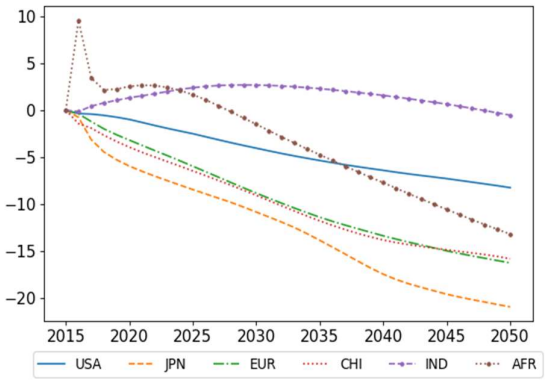
(a) Investment (%)



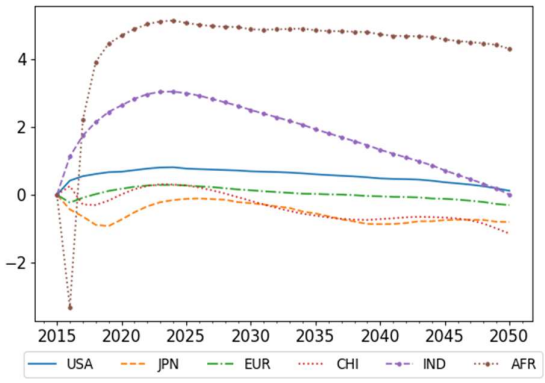
(b) GDP (%)



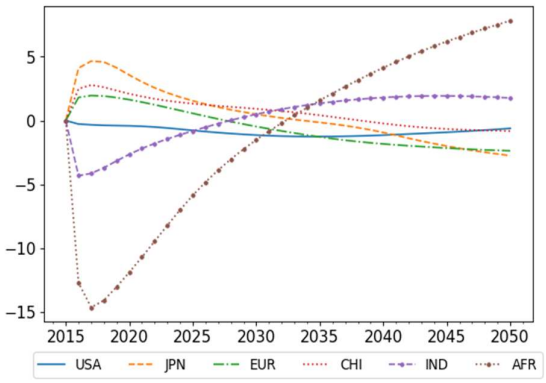
(c) Per Capita GDP (%)



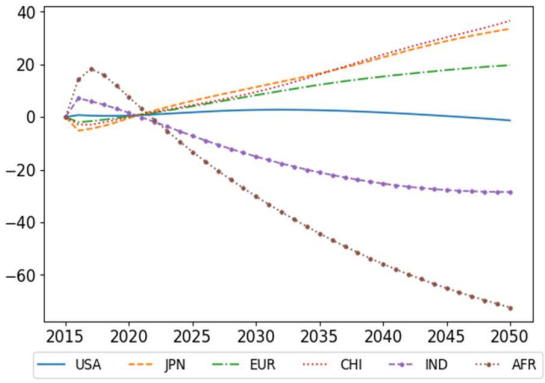
(d) Real Interest Rate (Percentage Point)



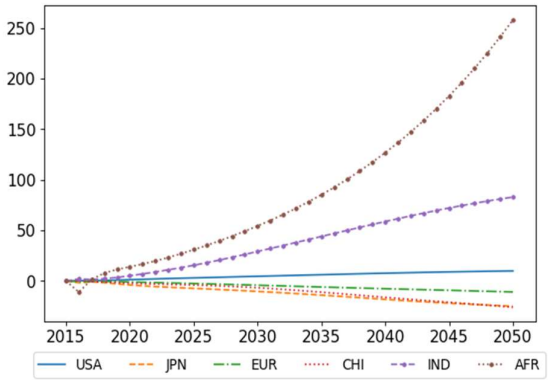
(e) Trade Balance (% of GDP)



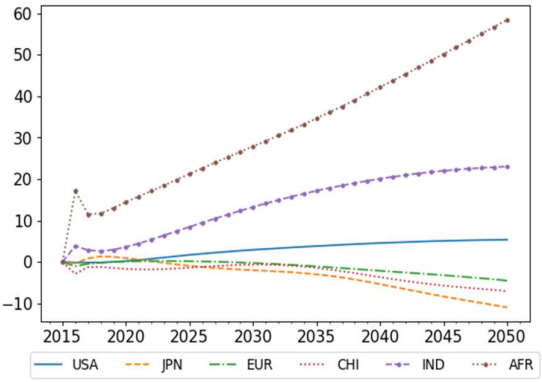
(f) Real Exchange Rate (%)



(g) Real Wage (%)



(h) Consumption (%)



(i) Per Capita Consumption (%)