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## The Global Impact of Demographic Change

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**IMF Working Paper**

Research Department

**The Global Impact of Demographic Change**

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**Abstract**

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The world is in the midst of a major demographic transition. This paper examines the implications of such transition over the next 80 years for Japan, the United States, other industrial countries, and the developing regions of the world using a dynamic intertemporal general equilibrium four-country model containing demographics calibrated to the “medium variant” of the United Nations population projections. We find that population aging in industrial countries will reduce aggregate growth in these regions over time, but should boost growth in developing countries over the next 20–30 years, as the relative size of their working-age populations increases. Demographic change will also affect saving, investment, and capital flows, implying changes in global trade balances and asset prices. We also explore the sensitivity of the results to assumptions about future productivity growth and country external risk for the developing country region.

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## I. INTRODUCTION

The world is in the midst of a major demographic transition. Not only is population growth slowing, but the age structure of the population is changing, with the share of the young falling and that of the elderly rising. Different countries and regions, however, are at varying stages of this demographic transition. In most advanced countries, the aging process is already well under way, and a number of developing countries in east and southeast Asia and central and eastern Europe will also experience significant aging from about 2020.<sup>2</sup> In other developing countries, however, the demographic transition is less advanced, and working-age populations will increase in the coming decades.<sup>3</sup>

This paper examines the economic implications of this demographic transition for Japan, the United States, other industrial countries (largely in Europe), and developing regions of the world using a four-country version of the MSG3 dynamic intertemporal general equilibrium model (or DSGE model from the macroeconomics literature) extended with an OLG Blanchard approximation. This model was developed by McKibbin and Nguyen (2004). The demographic transition is calibrated to the “medium variant” of the United Nations population projections. The model innovates upon existing OLG multicountry models by introducing a three-sector production technology, rule-of-thumb behavior, real and nominal rigidities, and different types of capital into more basic general equilibrium optimizing OLG setups. In doing this it brings together features of real business cycle models—with a fully articulated analysis of forward-looking producers and consumers—and modern macroeconomic DSGE models—describing the effects of demand downturns in the face of wage (and price) stickiness.

We find four main results:

- Population aging in industrial countries will reduce growth, beginning in Japan in the next decade and then the rest of other industrial countries by the middle of the century.
- In contrast, as the relative size of their working-age populations increases, developing countries will enjoy a “demographic dividend” that should result in stronger growth over the next 20–30 years, before aging sets in.
- Demographic change will also affect saving, investment, and capital flows. Japan and to a much lesser extent the other industrial countries—the fastest aging countries—could see large declines in saving and a deterioration in their current account positions as the elderly run down their assets in retirement.

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<sup>2</sup> The term developing countries in this paper refers to emerging market and other developing countries.

<sup>3</sup> An excellent overview of the issue facing developing countries can be found in Birdsall, Kelley, and Sinding (2001).

- Results are sensitive to assumptions made about productivity growth and external risk premia.

The paper is organized as follows. Section II summarizes key aspects of the current and expected global demographic transition. Section III reviews the recent literature that has explored the macroeconomic implications of demographic change and describes the model that we employ. Section IV presents our baseline results estimating the impact of demographic change from 2005 until 2080, and Section V examines how sensitive these are to the assumptions made about growth and risk assessment in developing countries. Conclusions and policy implications follow (Section VI). Details of the model and the calibration/estimation are contained in the appendix.

## II. SOME BACKGROUND ON GLOBAL DEMOGRAPHIC CHANGE

The world is in the midst of a historically unprecedented demographic transition that is having—and will continue to have—profound effects on the size and age structure of its population (Figure 1). Before 1900, world population growth was slow, the age structure of the population was broadly constant, and relatively few people lived beyond age 65. This began to change during the first half of the twentieth century as rising life expectancy boosted population growth, although initially there was little change in the age structure of the population.<sup>4</sup> The second half of the twentieth century saw the start of another phase in this transition. Fertility rates declined dramatically—by almost one-half—causing population growth to slow, the share of the young in the population to decline, and the share of the elderly to increase. The share of the working-age population, however, changed little.

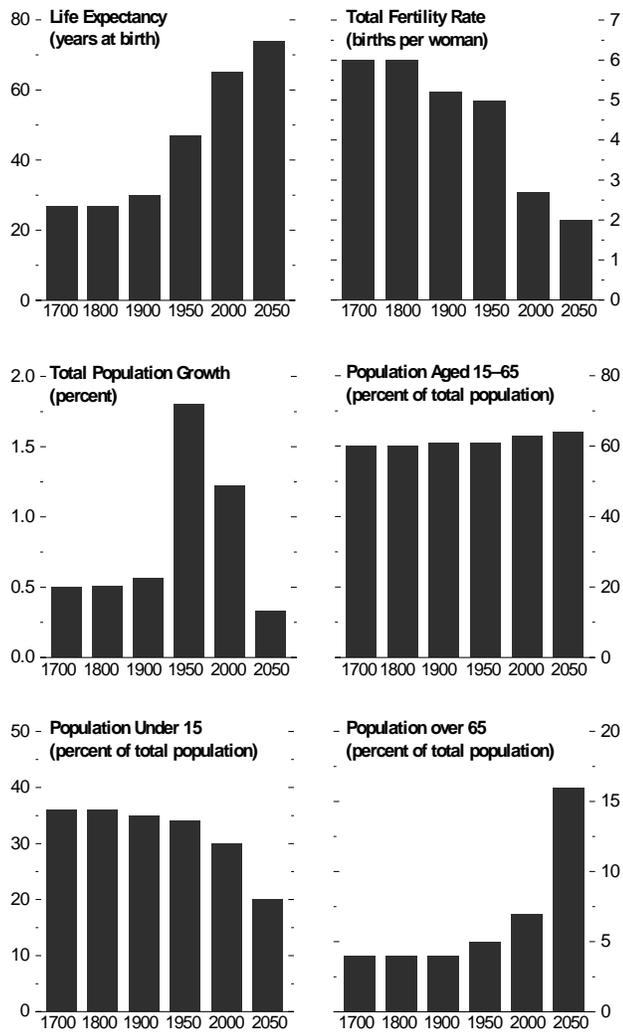
These global developments mask considerable variation between countries and regions that are the result of very different fertility, mortality, and migration trends. For example, although fertility rates have fallen almost universally in recent decades, they remain much higher in developing than in advanced countries, where they are generally below the replacement rate.<sup>5</sup> Even among developing countries, considerable differences exist—fertility rates are high in Africa and the Middle East, but are below replacement rates in east Asia and central and eastern Europe. Likewise, while life expectancy has risen across the globe over the past 50 years—and the largest gains have generally been made in developing countries—life expectancy still remains much higher in advanced countries. Exceptions to the generalized increase in life expectancy are Africa—where as a result of the HIV/AIDS

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<sup>4</sup>In a number of European countries, the demographic transition began much earlier. Lee (2003) dates the beginning of the decline in mortality in northwest Europe to about 1800.

<sup>5</sup> Replacement level fertility is estimated to be 2.1 births per woman in industrial countries and 2.4 births per woman in the developing countries. The level exceeds 2 in part because more boys are born than girls and in part because some children die before they reach reproductive age.

Figure 1. Global Demographic Transition, 1700–2050



Source: Lee (2003).

pandemic, life expectancy has declined by more than 25 percent in some countries—and the Commonwealth of Independent States (CIS) countries. Lastly, net immigration has made an important contribution to population growth in recent years in North America, but much less so in Europe and Japan.

As a consequence of all of these trends, population growth is much higher in developing countries—particularly in Africa and the Middle East—than in advanced countries. Indeed, in Japan and Europe, population growth is close to zero. The share of the young in the total population is also higher in developing countries, while the elderly account for a larger share of the population in advanced nations.

Looking ahead, the United Nations current population projections (which extend to 2050) envisage that fertility rates in low-fertility countries will recover modestly, that fertility in other countries will continue to decline, that further gains in life expectancy will be made in both advanced and developing country regions, and that migration will make an increasingly important contribution to total population growth in advanced countries, but will only modestly reduce population growth in developing countries.<sup>6</sup> This has the following consequences (Figure 2).

- *Global population growth will continue to slow.* By 2050, global population growth is projected to be only ¼ percent a year, compared with 1¼ percent at present. The population in a number of countries is actually expected to decline over the next 50 years, including by over 30 percent in some central and eastern European countries, by 22 percent in Italy, and by 14 percent in Japan. In developing countries—particularly in Africa and the Middle East, but also parts of Asia—population growth, although slowing, will remain robust, reflecting their higher fertility rates.
- *The world's population will continue to age.* The elderly will account for an increasing share of the population—although the pace and timing of aging varies widely between countries and regions—and the median age of the world is expected to increase by over 10 years during 2000–50 to 37 years. The elderly dependency ratio—which shows the population aged 65 and older as a share of the working-age (aged 15–64) population—is projected to rise dramatically in Japan and Europe, with lesser increases anticipated in the United States.<sup>7</sup> Among the developing country

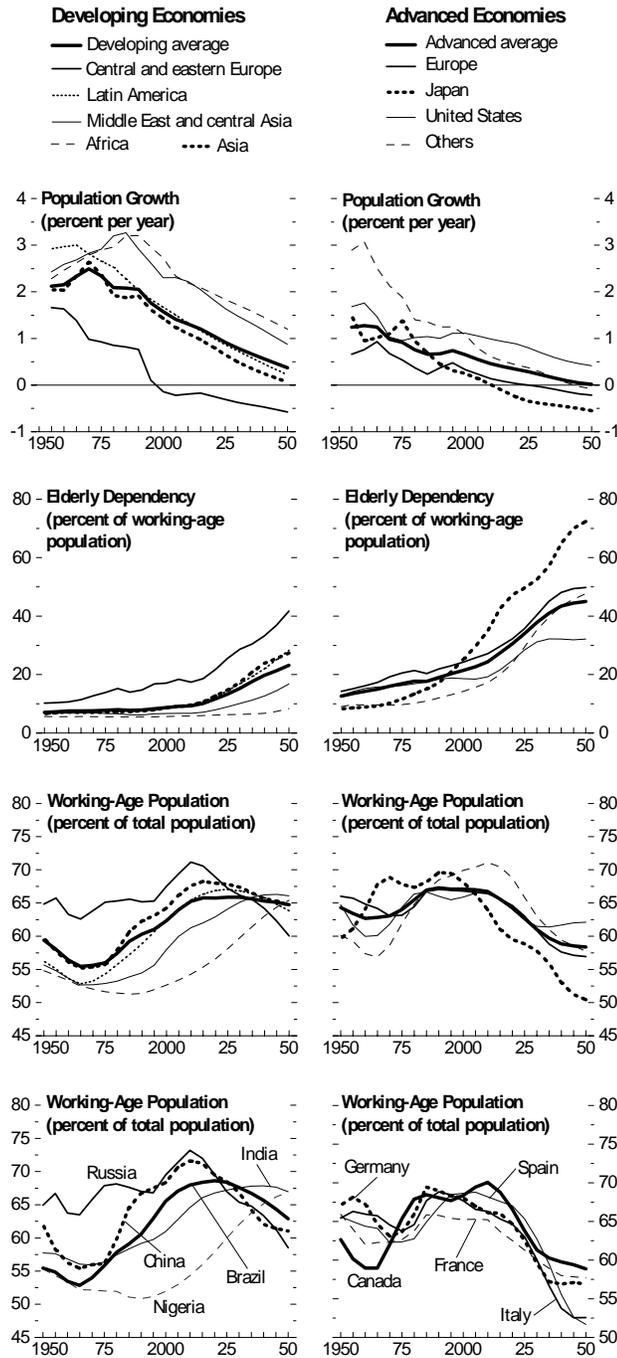
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<sup>6</sup> The projections discussed in this section refer to the “medium variant” of United Nations (2003).

<sup>7</sup> These elderly dependency ratios are only an approximation to the support needs of an elderly population. Some people continue to work after they have reached age 65, while not everyone in the 15–64 age group is in employment—they may be still in school,

(continued...)

Figure 2. Population Structure, 1950–2050



Source: United Nations, *World Population Prospects: The 2002 Revision* (2003).

unemployed, or outside the labor force. Further, in some countries, children younger than 15 are in full-time employment. It is possible to develop a measure of economic dependency that adjusts for these factors, but this alternative measure is difficult to calculate, particularly for developing countries.

regions, aging is already under way in central and eastern Europe, a process that is expected to accelerate from about 2015. Aging will also begin to accelerate in Asia and Latin America around this time—with China experiencing particularly rapid aging—but the share of the elderly in Africa and the Middle East, while rising, will remain relatively small.

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- *The share of the working-age population will fall in advanced countries, but increase in many developing countries.* In Japan and some European countries, this decline has already started and is projected to accelerate. In the United States, a high rate of immigration and higher fertility rates result in a more modest projected decline until 2025, after which the share of the working-age population stabilizes. In developing countries, the share of the working-age population is projected to increase until 2015, and then stabilize at this higher level as a declining share of the young offsets a rising share of the elderly.

The demographic changes that are projected to take place in the coming years are striking. Clearly, caution must be exercised when using long-term projections of any kind, and demographic projections do become much more uncertain the further into the future one goes. However, the basic trends outlined in this section—toward an increasing share of the elderly and a declining share of the young in the population—are apparent in most plausible scenarios, and the main issue therefore is the extent to which the global population will age over the next 50 years (and beyond). Against this background, it is important to understand how demographic change is likely to affect global economic and financial market outcomes.

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<sup>8</sup> These elderly dependency ratios are only an approximation to the support needs of an elderly population. Some people continue to work after they have reached 65, while not everyone in the 15–64 age group is in employment—they may be still in school, unemployed, or outside the labor force. Further, in some countries, children younger than 15 are in full-time employment. It is possible to develop a measure of economic dependency that adjusts for these factors, but this alternative measure is difficult to calculate, particularly for developing countries.

### III. MODELING THE ECONOMIC IMPACT OF DEMOGRAPHIC CHANGE

Numerous studies in the literature examine the impact of demographic change on one region of the world by simulating closed-economy multiple generation models. Multiple generation models of the kind used in these studies were first proposed by Samuelson (1958) and Diamond (1965). In their purest overlapping-generations (OLG) form, these innovate upon the Ramsey infinitely-lived representative-consumer hypothesis by introducing, at each point in time, individuals of different generations (see, for example, Auerbach and Kotlikoff, 1987). Work by Blanchard (1985), Buitier (1988), Weil (1989), and more recently Faruqee (2000, 2003) suggested simplified closed-economy alternatives to pure OLG models.

Multicountry extensions in the OLG tradition are relatively recent and include Buitier (1981), Cutler and others (1990), Faruqee, Laxton, and Symansky (1997), Attanasio and Violante (2000), INGENUE (2001), Brooks (2003), Börsch-Supan, Ludwig, and Winter (2003), McKibbin, and Nguyen (2003), Fehr, Jokisch, and Kotlikoff (2003), and Bryant and McKibbin (2004) among others. Results from such models differ according to the way household consumption, saving, and wealth accumulation are treated in each model, as well as whether the models incorporate frictions in the adjustment to equilibrium and whether and how they model fiscal (including pension schemes) and monetary policy arrangements.

The model used in this paper is a modified version of the MSG3 model. The MSG3 model is a three-sector—energy, nonenergy, and capital-producing—version of the G-Cubed model developed by McKibbin and Wilcoxon (1998). The model in this paper is much smaller than the original model because of the incorporation of demographic variables. In this version the world is divided into four regions: Japan, the United States, other industrial countries (largely in Europe), and the rest of the world (in essence, the world's developing bloc). It combines the modern intertemporal optimization approach to modeling economic behavior (as found in Blanchard and Fischer, 1989, and Obstfeld and Rogoff, 1996) with short-run rule-of-thumb behavior. In doing this, it brings together features of real business cycle models—with a fully articulated analysis of forward-looking producers and consumers—and modern macroeconomic models—describing the effects of demand downturns in the face of wage (and price) stickiness. The main features of the model are as follows.

- *Demographics.* The model includes demographic considerations, such that economic agents in the model possess finite lifespans and their income varies as they age. Specifically, this draws heavily on Faruqee (2003a, 2003b) who extended the Blanchard (1985) model of finitely lived agents to include aging considerations. Following Bryant and McKibbin (2004), we extend this approach to allow for children who are dependent on working parents for 17 years. These children then become adult at a maturity rate  $m$ . Each adult has age specific productivity that rises over their life and then gradually deteriorates towards zero as they age. These workers

are responsible for supporting their financially dependent children. Death occurs with a fixed probability.<sup>9</sup>

- *Explicit optimization.* The model is based on explicit intertemporal optimization by agents (consumers and firms) in each economy. Thus, time and dynamics are of fundamental importance in the MSG3 model, making its core theoretical structure like that of real business cycle models.
- *Rule-of-thumb agents.* To track the inertial dynamics of some key macroeconomic variables, the behavior of agents is modified to allow for short-run deviations from optimal behavior, owing either to myopia or to restrictions on the ability of households and firms to borrow at the risk-free bond rate on government debt.
- *Cash-in-advance constraints.* Holdings of financial assets including money are explicitly modeled. In particular, money is introduced into the model through a restriction that households require money to purchase goods.
- *Nominal rigidities.* The model allows for short-run nominal wage rigidity (by different degrees in different countries) and therefore allows for protracted periods of unemployment depending on the labor market institutions in each country.
- *Two types of capital.* The model distinguishes between the stickiness of physical capital within sectors and within countries and the flexibility of financial capital that can flow immediately where expected returns are highest. This distinction leads to a difference between the quantity of physical capital that is available at any time to produce goods and services and the valuation of that capital as a result of decisions about the geographical allocation of financial capital.
- *Estimation/calibration.* Key parameters in the model—such as the elasticities of substitution in production and consumption decisions—are estimated, enhancing the model’s ability to reproduce the dynamics of historical data.

As a result, the model exhibits a rich dynamic behavior, driven on the one hand by asset accumulation and, on the other hand, by wage adjustment to a neoclassical steady-state. The core equations of the model and a description of the data used in the calibration are available at [www.gcubed.com](http://www.gcubed.com).

We should stress at the outset that the fiscal sector in the model is articulated without a public pension scheme, and we therefore abstract from the fiscal side of the demographic debate. Throughout the analysis we assume that government expenditures are held constant as a share of GDP and that tax revenues fluctuate with changes in labor and corporate incomes. To the extent that fiscal deficits or surpluses emerge as a result of the demographic

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<sup>9</sup> See McKibbin and Nguyen (2004) for a complete discussion of the theory.

shocks we assume that a lump sum tax on households changes to finance the additional interest costs of any changes in government debt. Fiscal sustainability is imposed in this study so that we can focus on the macroeconomic adjustments to the demographic change.

#### **IV. HOW WILL DEMOGRAPHIC CHANGE AFFECT THE GLOBAL ECONOMY?**

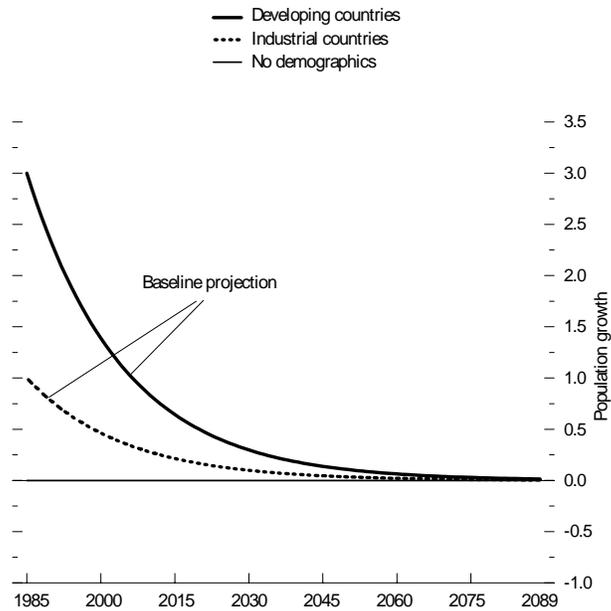
The demographic changes projected over the coming years are large, but are they likely to have an important effect on the economies of advanced and developing countries? This section reports simulations from the MSG3 model to assess this issue.

Our modeling approach is as follows. We first project the world economy from 1985 to 2100 assuming the UN mid-range demographic projection (converted into the equivalent model variables given by the analytical framework). We also make assumptions about productivity growth by sector and country using the approach outlined in Bagnoli, McKibbin, and Wilcoxon (1996) extended in McKibbin, Pearce, and Stegman (2004). This projection exercise gives us a baseline simulation containing the expected demographic transition. We then rerun the model removing the demographic transition from the model projection starting in 1985 (Figure 3). Removing the demographic transition is defined as setting the birthrates of adults and children equal to the rates assumed in the long-run steady-state at 2200. These rates are arbitrary, but not implausible. They assume a child birthrate of 1.9 percent and an adult maturity rate of 1.5 percent plus a constant probability of death of adults of 1 percent and of children of 0.46 percent. Due to the requirement of the modeling approach that there be a well defined steady-state with all countries growing at the same rate, we are forced to assume that all countries will eventually have the same demographics (in terms of growth rates) in the steady-state (however, this is centuries into the future). The period of the current demographic bulge, from 1985 until the steady-state, is interpreted as a temporary deviation from this long-run steady-state. Thus removing the temporary deviation also gives us a measure of the impact of the demographic transition over the recent past and into the future.

The process of removing a shock of this nature is not a conceptually easy exercise because the model assumes rational expectations in a variety of markets. Thus the initial conditions for 1985 (i.e., the actual data) in the baseline have expectations about the demographic transition already embodied in stock variables such as physical capital stocks, net asset positions (both domestic and foreign), and human capital. We thus have a problem in the counterfactual exercise that in 1985, when we remove the demographic shock, we are capturing both the impact of the underlying demographics as well as the impact of the change in expectations about future demographic change. For a period after the new information is realized, there will be a large adjustment in asset stocks which reflects the expectations revision. To try and separate out the expectations revision from the underlying demographic change, we let the model run for 20 years to 2005 so that much of this initial asset adjustment is completed and we are capturing more of the pure demographic effect and less of the revision to expectations. Thus in the following analysis all results are presented from 2005 to 2080 after the asset stock adjustment and asset price volatility to the change in information in 1985 have washed through the economy.

We convert the UN population projections (mid-case scenario) into the parameters of the model given the constant probability of death for adults and a different but constant probability of death for children. This is done in a way which gives us, as close as possible, the aggregate adult and child populations over time for each country as projected by the United Nations. It is not an exact representation of the UN projections because the probability of death is changing over time and at this stage of the research we are unable to incorporate this. Thus the results should be interpreted as illustrative rather than as precise predictions about the future.

**Figure 3. Removing the Demographics (a Stylized Representation)**



Sources: Authors' estimates

Figure 4 presents the deviation of the child birth- rate and adult maturity rates from the long-run steady-state rates. These are the basic shocks that are removed from the baseline in the counterfactual simulation. Several important points can be seen in these figures. In the United States and the developing country bloc, the child birthrates and adult maturity rates, although declining, are well above the rates in their steady-state rates and populations are rising. For Japan and the other industrial countries, child birthrates and adult maturity rates are currently below steady-state levels, and populations are falling. The pace at which child birthrates and adult maturity rates are declining, however, are faster in developing countries, and in this important sense the demographic transition in developing countries is greater than in the advanced regions.

Results for the impact of demographic change on the global economy for the period from 2005 to 2080 are shown in Figure 5. Each figure contains results for each of the four regions showing the estimated impact of demographic change—that is, the difference between the baseline which includes demographic change and an alternative scenario in which the demographic variables are at their steady-state rates of growth. The results are expressed in such a way that a positive number is a variable which is higher because of the impact of changing demographics than it would otherwise have been. For example, the level of Japanese GDP in 2050 is estimated to be 30 percent lower than would have been the case without the impact of the demographic transition—the decline in the labor force is only partly offset by a higher capital stock (see below). On the other hand, developing country GDP is estimated to be 60 percent higher by 2050 as a result of the strong increase in the labor force due to the demographic transition. It is important to stress that results for all countries depend on the demographic change in each country and the spillover between countries.<sup>10</sup>

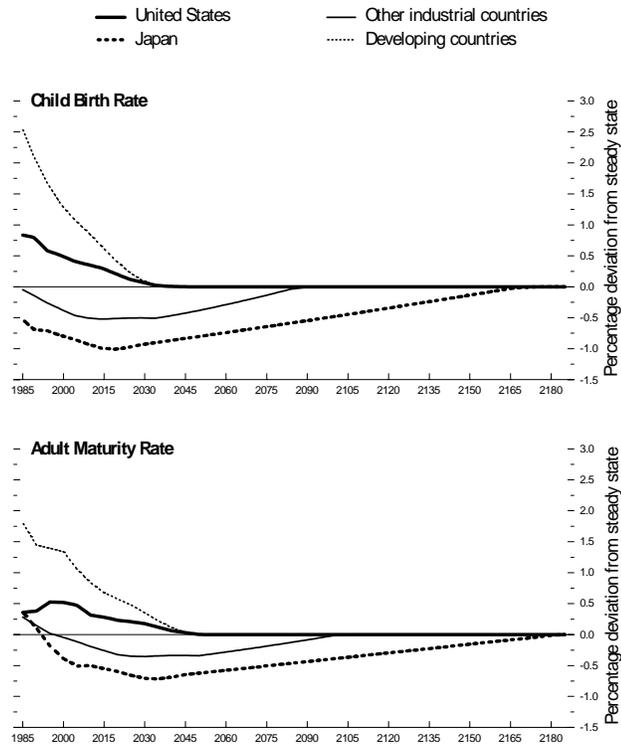
In Figure 5 it is clear that the demographic transition is important in affecting the GDP growth rate, with growth in developing countries more than 2 percent higher by 2020 than without the demographic change, and growth falling in Japan after 2010 to reach a low point of 1.3 percent below the situation in the “no demographic change” scenario by 2040. The United States and the other industrial countries are intermediate between these cases, although it should be stressed that within Europe and within developing countries there are also large differences in demographic outcomes which are averaged away in the aggregation we are using in this paper.<sup>11</sup> The picture per adult (the proxy for per capita in the model) is quite different to that for the real growth rate. The Japanese outcomes are a point to note. GDP per adult is projected to be higher in Japan out to 2025 and still be above what would

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<sup>10</sup> The relative impact of own and cross border demographic change is considered further in McKibbin (2005).

<sup>11</sup> This is explored further in McKibbin (2005) where the other industrial countries and developing country blocs are further disaggregated.

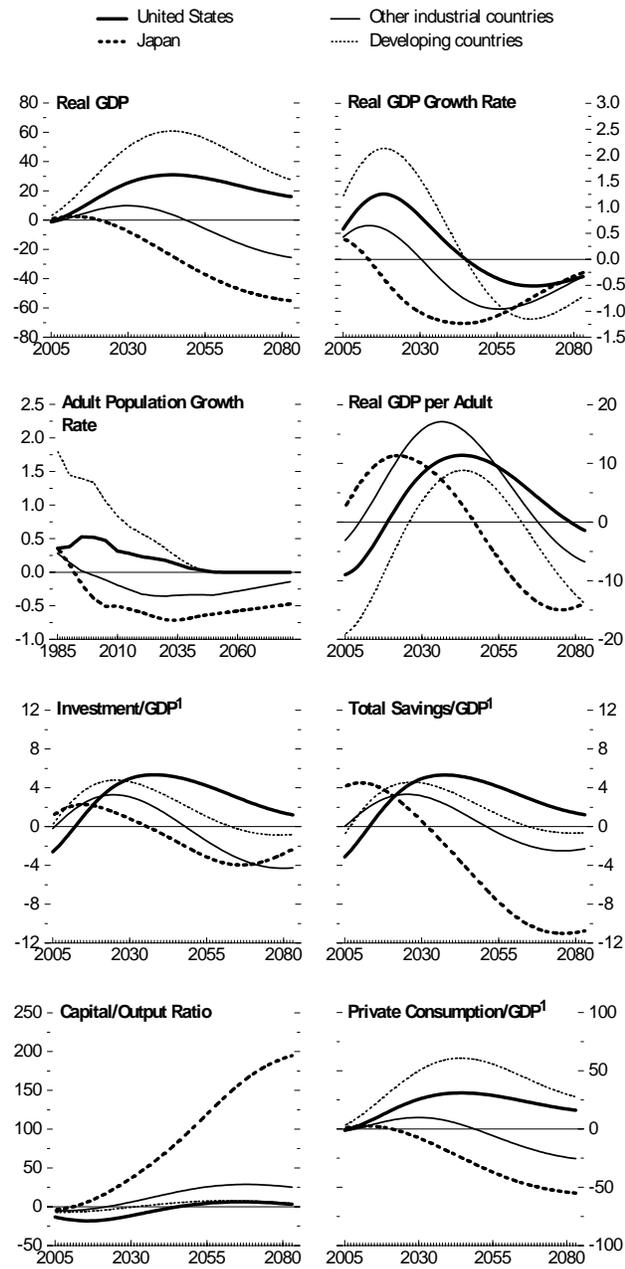
**Figure 4. Child Birth and Adult Maturity Rate (Relative to Steady State)**



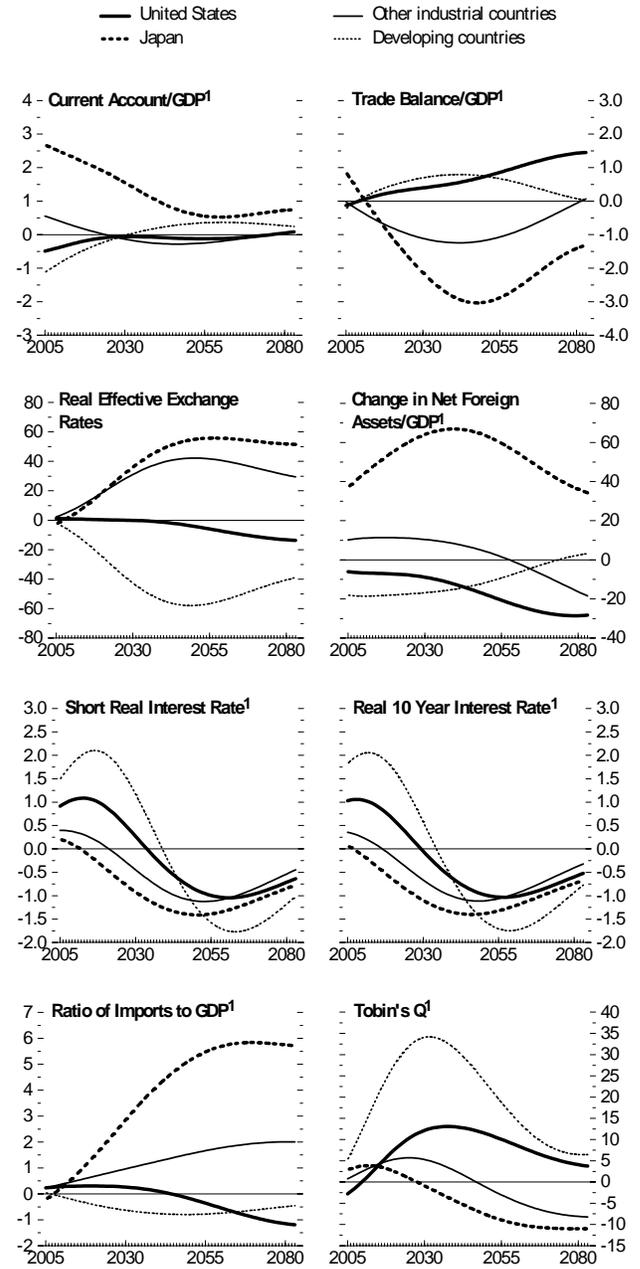
Sources: Authors' estimates

**Figure 5. Impact of Global Demographic Transition - 4 Region MSG3 Model**

(Percent deviation from baseline unless otherwise noted)



**Figure 5. Impact of Global Demographic Transition - 4 Region MSG3 Model (concluded)**



Source: Authors' estimates  
<sup>1</sup>Percent point deviation from baseline.

have been experienced until 2050. This demonstrates that in a world with falling labor forces it is important to focus on per capita variables rather than aggregate variables in thinking through the welfare impacts of demographic change.

As expected, the changing population and labor force have important impacts both on private investment through changes in the expected marginal product of capital as well as on consumption and saving decisions. The increase in the labor force in developing countries raises the marginal product of capital and stimulates higher investment, with the investment to GDP ratio 4 percent higher by 2025. There is also initially an increase in investment in Japan as a result of the need to substitute capital for a diminishing supply of workers over time, although eventually investment begins to fall as the declining labor force needs less capital to equip it. The substitution of workers with capital is clear in the change in the capital output ratio in Japan.

The response of households to both a change in youth dependency and an expected change in elderly dependency can also be seen. In Japan, private saving has been boosted in recent years as the working age population move through their high saving years, but is projected to fall over time as the increasing number of elderly disserve to supplement their falling employment income. The ratio of saving to GDP is 4 percentage points higher by 2005 due to the demographic transition, but by 2070 is projected to be 11 percentage points lower. In the United States, the saving-to-GDP ratio in 2005 is 3 percentage points lower due to demographic changes, but is projected to be 5 percentage points higher by 2040 as an increasing number of the population move into their high saving years. Aggregate private consumption reflects these trends with consumption rising in developing countries (and to a lesser extent in the United States) and falling in Japan. Per capita consumption (not shown), however, actually rises initially in Japan and is only slightly lower by 2050.<sup>12</sup>

It is clear that the demographic transition has important effects on saving and investment behavior and consequently current account balances. As a result of the demographic transition occurring both in Japan and the rest of the world, the Japanese current account in 2005 is 2.6 percent of GDP in surplus relative to the case of no demographic change. Over time, however, as saving falls in Japan, and there is a rise, then fall, in investment, the current account surplus narrows. The current account position also deteriorates—albeit more modestly in the other industrial countries—while the United States and developing countries see an improving current account position. These changes result in a substantial reallocation of global capital, as Japan and the other industrial countries repatriate capital to maintain consumption in the face of falling labor incomes. These changes in current account positions are consistent with the results presented in IMF (2004) from simulations of the INGENUE model (2001) and econometric estimates. It is also worth noting here that the changes in saving behavior in the simulations here are not dissimilar to

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<sup>12</sup> See McKibbin and Nguyen (2004) for detailed discussion of the per capita behavior.

those from the INGENUE model (although in the later model the decline in saving in Europe is larger due to the explicit inclusion of a pension system in the model).<sup>13</sup>

The global asset adjustment is reflected in real exchange rates as a result of demographic change. There are a number of factors driving real exchange rates in this model.<sup>14</sup> A key factor is the assumption that all goods enter into consumers' consumption bundles identified by country of origin. Thus, if the supply of goods from one country shrinks, the relative price of those goods will tend to rise, taking all other factors as given. Thus, as the labor force falls in Japan and less Japanese goods are produced, the relative price of all Japanese goods will tend to rise. This will be reflected in an appreciation of the real exchange rate of Japan. By 2050 the Japanese real exchange rate is appreciated by close to 60 percent. Similarly, the real exchange rate of developing countries is depreciated by close to 60 percent because of the large increase in supply of developing country goods on world markets. In addition to these underlying factors, the adjustment of global capital flows will also tend to reinforce this effect. With income being repatriated back into countries with aging populations from countries with expanding populations, the real exchange rate of the aging economies will also tend to appreciate.

Finally, real interest rates in developing countries are 1.5 percent (150 basis points) above what they would have been because of demographic change, reflecting the rising marginal product of capital as the labor force rises in these economies. This is not arbitrated away because of adjustment costs in physical capital accumulation that prevent large differences in marginal products of capital from being exploited because developing countries cannot quickly absorb large amounts of capital. This differential is reduced over subsequent decades. In Japan, the changing capital-labor ratios as a result of demographic change is estimated to reduce real interest rates by up to 1.5 percent by 2050. Long-term interest rates fall much sooner than this given the expectations in the model. At the same time, equity markets summarized by Tobin's  $q$  (lower right-hand corner) are expected to rise especially in developing countries, again reflecting the changing marginal product of capital over time. In Japan and the other industrial countries as the demographic transition matures, equity markets fall below what they would have been by 2020 in Japan and 2040 in the other industrial countries.<sup>15</sup>

Overall, these results suggest that the demographic transition is already, and will increasingly, impact global growth and the distribution of this growth across regions. Saving, investment, and current account balances in different regions will also be affected. Clearly,

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<sup>13</sup> Social security contributions have to be raised to finance the large increase in pension expenditures in Europe. This effectively transfers resources from the working-age population—which has a higher propensity to save—to the older generations who have a lower propensity to save in the model.

<sup>14</sup> See Bryant and de Fleurieu (2005) for a detailed analysis of the exchange rate sensitivity to a wide variety of assumptions.

<sup>15</sup> See IMF (2004) for an overview of how population aging may affect financial markets.

there are a myriad of assumptions underlying the model used in this analysis. The following section puts the magnitudes of these results in the context of some other assumptions that might impact the variables that have been explored in this section.

## V. SENSITIVITY ANALYSIS

In this section, we change some assumptions both to see how important these might be for the analysis above, as well as to give a benchmark to compare the size of the adjustments we have presented in the previous section. The first assumption we explore is what happens if productivity growth outside the United States grows faster for a decade from 2005. The second assumption we explore is what happens if there is a fall in the country risk premium facing developing countries (which is benchmarked in the model to that in 1985).

### A. Faster Global Growth through More Rapid Technological Convergence

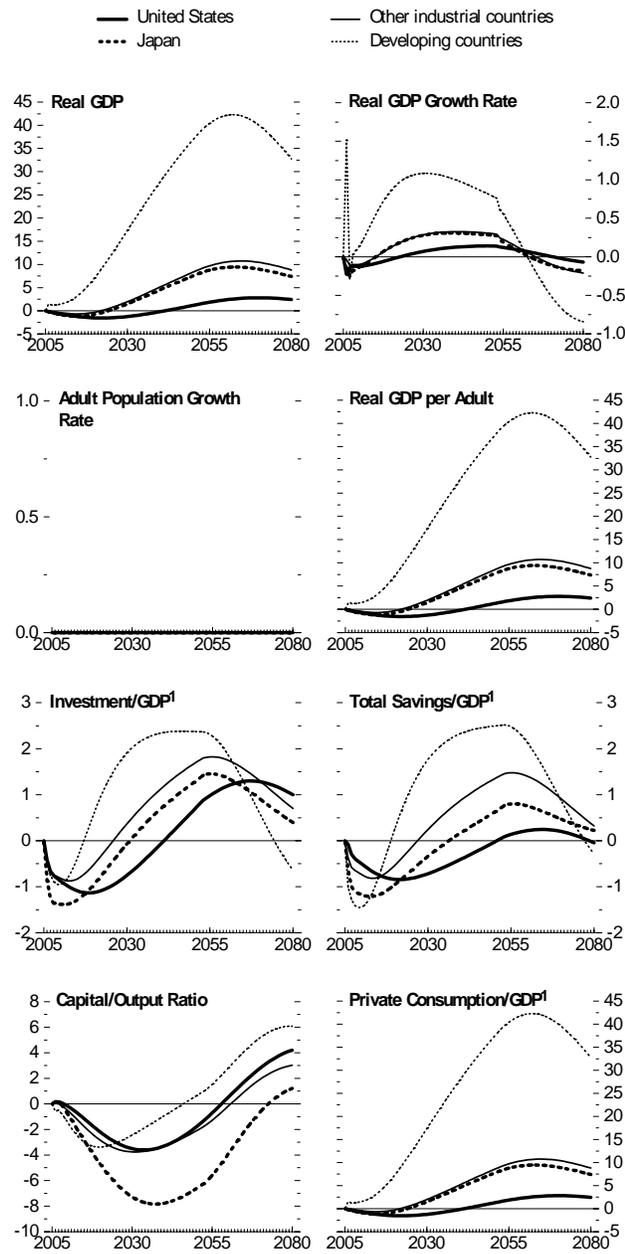
In this section we explore the implications of more rapid technological convergence than in the underlying baseline projection. This is modeled as a rise in productivity growth (defined as labor-augmenting technical change) of 1 percent per year for 50 years from 2005 to 2054 in the developing country region, a rise of 0.1 percent per year over the same time in Japan and other industrial countries, and no change in underlying productivity growth from baseline in the United States.

Results are presented in Figure 6 for the same set of variables as for the demographic shock. As expected, faster technical change leads to higher real GDP over time. In developing countries this growth begins immediately, although for the rest of the world GDP growth is actually slightly lower as resources are initially channeled into developing countries. This can be seen in the deterioration of the developing country current account. After a decade, however, real GDP growth rises in the rest of the world, with Japan and the other industrial countries experiencing their own growth from domestic productivity as well as income growth from stronger activity in developing countries.

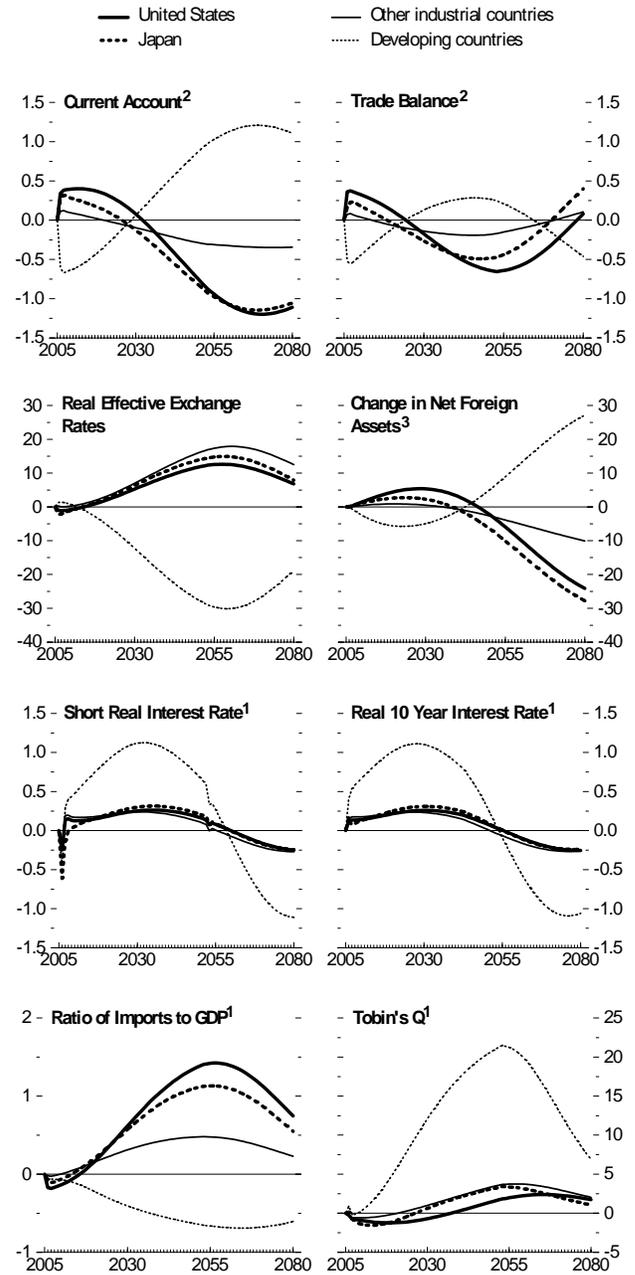
The surge in growth initially reduces investment in all countries. This may seem surprising, but it reflects the rise in consumption by households in anticipation of higher future income which reduces savings and raises real interest rates thereby crowding out private investment. It takes a decade before investment rates rise above the baseline in developing countries. This rise of consumption in anticipation of higher incomes and the initial fall in investment results in a fall in capital-output ratios in all countries (which is consistent with higher real interest rates). Higher real interest rates persist for five decades while productivity growth is high, but then fall below baseline when the growth surge concludes. This overshooting of interest rates reflects the overshooting of capital accumulation which can be seen in the sharp investment reversal after 2050. Despite the presence of rational consumers and firms in the model, there is also considerable persistence through the presence of backward-looking households and firms.

**Figure 6. Implications of Faster Productivity Growth for 50 Years - 4 Region MSG3 Model**

(Percent deviation from baseline unless otherwise noted)



**Figure 6. Implications of Faster Productivity Growth for 50 Years - 4 Region MSG3 Model (concluded)**



Source: Authors' estimates

<sup>1</sup>Percent point deviation from baseline.

<sup>2</sup>Change as percent of baseline GDP.

<sup>3</sup>Percent of baseline GDP.

In comparison with the results for the demographic transition, we can make several observations. The first is that higher productivity growth in developing and modestly higher productivity growth in developed economies can offset the impact of demographic change on aggregate GDP. Higher productivity growth of 0.1 per year in Japan and the other industrial countries offsets half of the fall in GDP caused by demographic change. For developing countries, the higher growth rate almost removes the expected future decline in growth rates caused by their aging after 2030. This is also true for the aggregate consumption outcomes. It does, however, place more upward pressure on real interest rates in the short run.

### **B. Improving Capital Market Access for Developing Countries**

Reforms to improve the investment climate are assumed to result in a reduction in the risk premium associated with investing in developing country assets. The risk premium is assumed to be 1 percent lower forever.<sup>16</sup> Figure 7 shows the results for the same set of variables as in the earlier figures. The reduction in the risk premium encourages more capital to flow into developing countries, and this reduces real interest rates and has a considerable impact on real GDP. Domestic saving increases for several decades in the developing countries as the rate of return on domestic capital improves as a result of the reforms, further reinforcing the positive effect on growth. The current account position of developing countries deteriorates, while the advanced country regions—the suppliers of the capital to the developing countries—experience improvements in their external balances. The change in risk premia relocates production from the industrial economies to the developing countries causing the capital output ratio to rise in developing countries and fall in industrial countries.

In comparison with the growth shock, the transmission of growth from developing countries' productivity is more positive for industrialized economies than the fall in developing country risk which leads to a reallocation of global production and higher global income, but all of the gains are captured by consumers in developing countries.

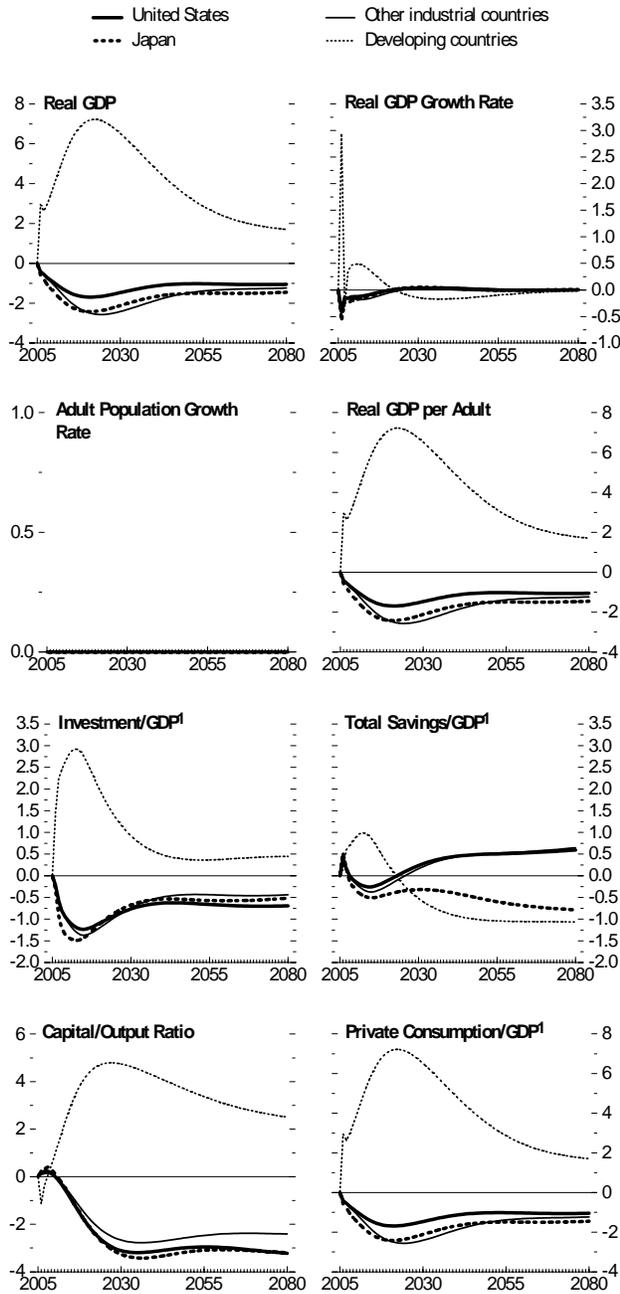
## **VI. CONCLUSIONS AND POLICY IMPLICATIONS**

The impact of ongoing demographic shifts across the globe will be wide-ranging. The modeling in this paper suggests that in advanced countries, population aging will likely reduce per capita growth rates in the future, while in developing countries increases in the relative size of the working-age population could lead to stronger per capita growth provided the additional labor resources are effectively utilized. International capital flows could also be substantially affected. The results presented in this paper suggest that large changes in saving, investment, and current account balances could take place over the next 80 years as a result of demographic change.

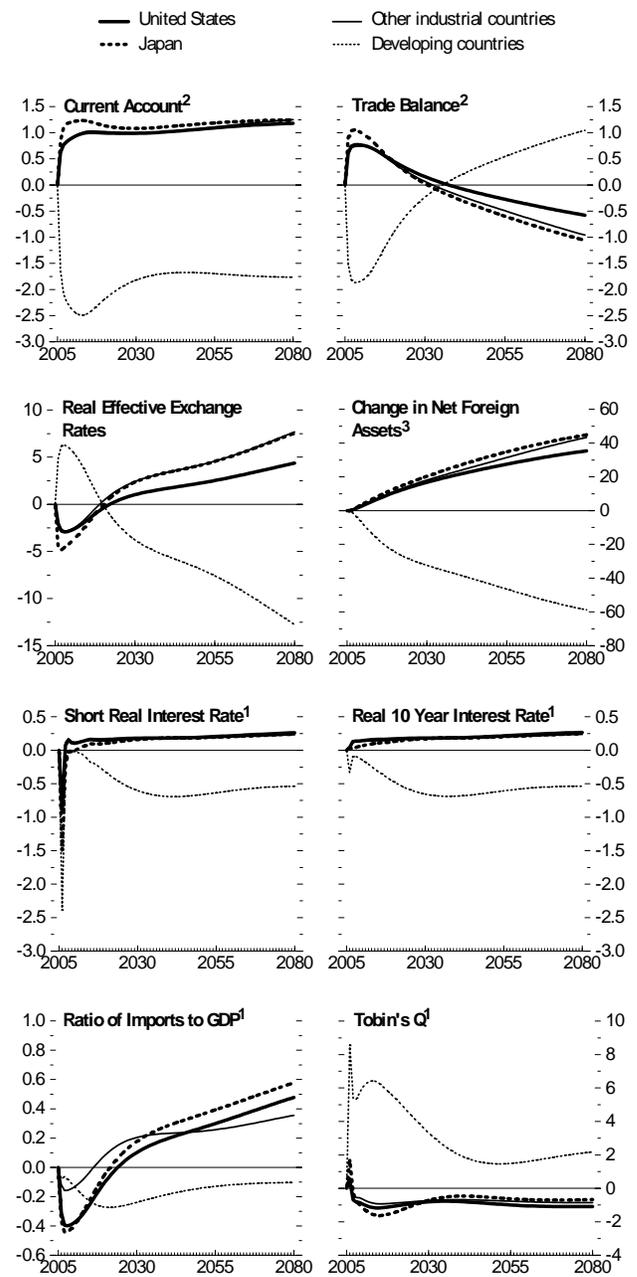
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<sup>16</sup> The issue of changes in country and equity risk premia using the same model but without demographics is considered in McKibbin and Vines (2003).

**Figure 7. Implications of One Percent Point Decline in Developing Country Risk - 4 Region MSG3 Model**  
*(Percent deviation from baseline unless otherwise noted)*



**Figure 7. Implications of One Percent Point Decline in Developing Country Risk - 4 Region MSG3 Model**  
**(concluded)**



Source: Authors' estimates  
<sup>1</sup>Percent point deviation from baseline.  
<sup>2</sup>Change as percent of baseline GDP.  
<sup>3</sup>Percent of baseline GDP.

There are, however, considerable uncertainties, and our understanding of how demographic change will affect economic performance is far from complete. For example, the impact of demographic change on external balances and capital flows will critically depend on the reaction of private saving, but it remains unclear to what extent households will adjust their behavior as the demographic transition unfolds. Further, the size of the potential changes need to be considered in the context of the scale of a wide range of other shocks that might occur in coming decades such as changes in productivity growth in various countries. It is clear that substantially more research is required to explore these issues.

## Appendix: The Analytical Approach

This appendix summarizes the analytical approach followed in incorporating demographics into the model. A summary of the key features of the MSG3 model was outlined in section III. More detailed documentation can be found in McKibbin and Wilcoxon (1998) and McKibbin and Nguyen (2004), as well as at [www.gcubed.com](http://www.gcubed.com).

### Adult Population

In each period, a cohort of children matures and joins the adult population. The size of the newly matured cohort, at time  $s$ , with respect to the existing adult population,  $N(s)$  is referred to as the maturity rate,  $b(s)$ . The maturity rate and its relationship to the population of children will be addressed in another section, below. Following Blanchard, we make the simplifying assumption that at any time  $s$ , all adults in the economy face the same mortality rate,<sup>17</sup>  $p$ , defined here as the probability of any given agent dying before the next period. The number of adults who matured at a previous time  $s$ , who are still alive at a subsequent time  $t$  is given by:

$$n(s, t) = b(s)N(s)e^{-p(t-s)} \quad (1)$$

The adult population size can then be determined for any time  $t$  by summing the number of living adults from all of the cohorts that have ever matured:

$$\begin{aligned} N(t) &= \int_{-\infty}^t n(s, t) ds \\ &= \int_{-\infty}^t b(s)N(s)e^{-p(t-s)} ds \end{aligned} \quad (2)$$

where  $N(t)$  represents the adult population size, at time  $t$ .

Taking the derivative with respect to time yields an equation governing the evolution of the adult population size over time:

$$\frac{\dot{N}(t)}{N(t)} = b(t) - p \quad (3)$$

The above equation has a simple interpretation: the adult population grows at a rate determined by the maturity rate less the mortality rate.

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<sup>17</sup> Blanchard (1985) notes that the assumption of a common mortality rate is a reasonable approximation for adults within the ages of 20 to 40. The fact that children and retirees, whose behavior is of interest in studies of population aging, fall outside of this age bracket certainly indicates that the issue requires further attention.

### Child Population

In every period, a cohort of children is born. If we think of the adult population as representing the set of potential parents, then it follows that the size of a newly born cohort will depend upon the current adult population size and the birthrate,  $b_m$ . The expression for the number of children born at time  $s$  who are still alive at a later time  $t$ , is thus given by:

$$m(s, t) = b_m(s)N(s)e^{-p(t-s)} \quad (4)$$

The aggregate number of children,  $M(t)$ , can be calculated by summing the number of surviving children, who were born recently enough that they have not yet reached adulthood. If we let  $\Delta$  represent the fixed number of years from when a child is born to when it reaches adulthood, i.e. the period of childhood,<sup>18</sup> then:

$$M(t) = \int_{t-\Delta}^t m(s, t) ds \quad (5)$$

$$M(t) = \int_{t-\Delta}^t b_m(s)N(s)e^{-(t-s)p} ds \quad (6)$$

Differentiating with respect to time:

$$\dot{M}(t) = -pM(t) + b_m(t)N(t) - b_m(t-\Delta)N(t-\Delta)e^{-p\Delta} \quad (7)$$

(Note that in the final exponential,  $p\Delta$  refers to the period of childhood multiplied by the mortality rate, it does not represent a change in  $p$ .)

### Relationship between the Birthrate and the Maturity Rate

Of the children who were born at time  $t-\Delta$ , those who survive will mature at time  $t$ , at which time they are added to the adult population. Thus, the maturity rate at time  $t$  is dependent on the birthrate, and adult population size, of  $\Delta$  years past; as well as the mortality rate.

$$b(t)N(t) = b_m(t-\Delta)N(t-\Delta)e^{-p\Delta} \quad (8)$$

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<sup>18</sup> In the simulations that follow, the period of childhood is defined as the first 16 years of an agent's life.

Now, we know that:

$$\begin{aligned} N(t - \Delta) &= N(t) e^{-\int_{t-\Delta}^t b(s) - p \, ds} \\ &= N(t) e^{p\Delta - \int_{t-\Delta}^t b(s) \, ds} \end{aligned} \quad (9)$$

so given the birthrate of  $\Delta$  years ago, and the maturity rates over the last  $\Delta$  years, the current maturity rate can be determined:

$$b(t) = b_m(t - \Delta) e^{-\int_{t-\Delta}^t b(s) \, ds} \quad (10)$$

Since the maturity rates over the last  $\Delta$  years will be dependent on previous values of the birthrate, it is clear that the rate of maturity is predetermined by any given series of birthrates.

### Adult Consumption

Adults attempt to maximize the expected utility derived from their lifetime consumption. Adults must take into account the uncertainty of their life spans and thus they discount their planned future consumption by the probability that they may not survive through to future periods. Assuming a logarithmic utility function, each agent will maximize the following:

$$\max \int_t^\infty \ln c(s, v) e^{-(\theta+p)v} \, dv \quad (11)$$

subject to the budget constraint:

$$\dot{w}(s, t) = [r(t) + p]w(s, t) + y(s, t) - c(s, t) \quad (12)$$

where  $c(s, t)$  is the consumption, at time  $t$ , of an adult who matured at time  $s$ ,  $\theta$  is the rate of time preference,  $w(s, t)$  is the financial wealth that an adult who matured at time  $s$  holds at time  $t$ ; and  $r(t)$  is the interest rate earned on financial wealth. Financial wealth includes domestic bonds, equity, and foreign assets from all countries in the models. In addition to interest payments, adults also earn a rate of  $p$  on their holdings of financial wealth, due to the assumption of a life insurance market, as in Blanchard (1985). Children do not play a part in the life insurance market, nor do they earn interest, as they are assumed to hold no financial wealth. In the full model the  $c(s, v)$  function also includes a complete set of all goods from all countries in the models. Within each period, once aggregate consumption for that period is determined, the allocation across goods from different countries is determined based on relative prices of goods distinguished by place of production.

The optimal consumption path for an adult can be shown to be:

$$c(s, t) = (\theta + p)[w(s, t) + h(s, t)] \quad (13)$$

where  $c(s, t)$  is the consumption, at time  $t$ , of an adult who matured at time  $s$ , and  $h(s, t)$  represents the human wealth of the adult. An adult's human wealth is defined as the present value of the adult's expected income over the remainder of his or her lifetime:

$$h(s, t) = \int_t^{\infty} e^{-\int_t^v r(i)+p di} y(s, v) dv \quad (14)$$

At any time  $t$ , the sum of financial wealth and human wealth— $w(s, t)$  and  $h(s, t)$ —represents an adult's total wealth: the means by which the adult can pay for his or her future consumption. Adults consume a proportion of their total wealth each period, the proportion being determined by their rate of time preference, and their likelihood of perishing before the next period.

Aggregate adult consumption, aggregate financial wealth, and aggregate human wealth are simply the sums of the consumption, financial wealth, and human wealth for all adults in the economy.

$$C_N(t) = \int_{-\infty}^t c(s, t)n(s, t) ds \quad (15)$$

$$W(t) = \int_{-\infty}^t w(s, t)n(s, t) ds \quad (16)$$

$$H(t) = \int_{-\infty}^t h(s, t)n(s, t) ds \quad (17)$$

where  $C_N(t)$  represents aggregate adult consumption,  $W(t)$  is aggregate financial wealth, and  $H(t)$  is aggregate human wealth.

The adult aggregate consumption function can be shown to be given by:

$$C_N(t) = (\theta + p(t))[W(t) + H(t)] \quad (18)$$

### **Labor Supply and Demographic Considerations**

Empirically, one of the key economic characteristics that changes with age is the income that a person receives. This is usually summarized in an age-earnings profile of a country. We introduce age-earnings profile into the model, such that an agent's income is determined by his or her age. We then aggregate cohorts over time. Further, we assume that only adults earn labor income and that children are completely dependent upon adults. Faruquee (2000) utilizes hump-shaped age-earnings profiles for adults, fitted to Japanese data using nonlinear least squares (NLS). Intuitively, the hump-shaped profile of age-earnings

reflects the fact that young adults generally have incomes that are increasing as the young individuals age and gain more experience. After a certain age, however, earnings decline, reflecting first the decreasing productivity associated with aging, and then eventually reflecting retirement behavior.

Individual income is not specified as suddenly dropping to zero, at a given retirement age, for two reasons. Firstly, in practice, people typically retire at various ages, and some retirees continue to earn alternative forms of income even after retirement. Secondly, a discontinuous age-earnings profile introduces complications with respect to implementation in the model.

We model the evolution of income over the lifecycle by beginning with the assumption that individuals are paid a wage for each unit of effective labor that they supply. We also assume that effective labor supply is a function of an individual's age and of the current state of technology. Aside from aging considerations, note that as time passes, the technological progress in the economy has a positive effect on the value of effective labor supplied by all agents.

The effective labor supply, at time  $t$ , of an agent who has been an adult since time  $s$ , is given by:

$$l(s,t) = e^{\mu t} [a_1 e^{-\alpha_1(t-s)} + a_2 e^{-\alpha_2(t-s)} + (1 - a_1 - a_2) e^{-\alpha_3(t-s)}]; \quad (19)$$

$(a_i > 0, \alpha_i > 0 \text{ for } i=1 \text{ to } 3)$

The  $e^{\mu t}$  component (where  $\mu$  is the rate of technological progress) captures productivity increases due to advancements in technology. The remaining terms represent the nonlinear functional form used to estimate the hump-shaped profile. The  $a_i$  and  $\alpha_i$  parameters are estimated, based on empirical data, using NLS.<sup>19</sup> The hump-shaped effective labor supply specification will in turn lead to a hump-shaped age-earnings profile.

Individual labor supply can be re-written as:

$$l(s,t) = \sum_{i=1}^3 l_i(s,t) \quad (20)$$

where:

$$l_i(s,t) = e^{\mu t} a_i e^{-\alpha_i(t-s)}; \quad (a_i > 0, \alpha_i > 0) \quad (21)$$

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<sup>19</sup> Values used in this paper for Japan are as estimated by Faruqee for Japan:  $\alpha_1 = 0.073$ ,  $\alpha_2 = 0.096$ ,  $\alpha_3 = 0.085$  and  $a_1 = a_2 = 200$ . In the theoretical model, to be consistent with Bryant (2004) we use the U.S. parameters for both countries:  $\alpha_1 = 0.08152$ ,  $\alpha_2 = 0.12083$ ,  $\alpha_3 = 0.10076$  and  $a_1 = a_2 = 200$ .

and:

$$a_3 = (1 - a_1 - a_2) \quad (22)$$

Thus, the evolution of an adult's labor supply over time is given by:

$$\dot{l}(s, t) = \sum_{i=1}^3 (\mu - \alpha_i) l_i(s, t) \quad (23)$$

Aggregate effective labor supply in the economy for any time  $t$ ,  $L(t)$ , is the sum of the effective labor supplied by all adults in the economy:

$$\begin{aligned} L(t) &= \int_{-\infty}^t n(s, t) l(s, t) ds \\ &= \sum_{i=1}^3 L_i(t) \end{aligned} \quad (24)$$

where:

$$L_i(t) = \int_{-\infty}^t n(s, t) l_i(s, t) ds \quad (25)$$

It can then be shown that:

$$\begin{aligned} \dot{L}(t) &= L_1(t) + L_2(t) + L_3(t) \\ &= (\mu - \alpha_1 - p)L_1(t) + (\mu - \alpha_2 - p)L_2(t) + (\mu - \alpha_{3i} - p)L_3(t) + e^{at} b(t) N(t) \end{aligned} \quad (26)$$

The intuition behind the equation above is that the aggregate labor supply of the economy changes as the entire population ages, and also as new agents mature into the labor force.

In the application in this paper we use the estimate age earnings profile for Japan and the estimate U.S. age-earnings profile for all other regions. This is a crude approximation in lieu of getting sufficient data to estimate a more extensive set of age-earnings profiles.

### **Intergenerational Transfers**

In our stylized model, children differ from adults, in that they do not provide labor supply (and thus do not receive payment for labor) and they do not hold financial wealth. Children are dependent upon their parents; each child receives an intergenerational transfer every period,  $c(t)$ , which is completely consumed by the child. As they do not make any consumption decisions, but rather just entirely consume their transfer, we do not need to account for their human wealth.

We assume that  $c(t)$  grows at the rate of productivity growth,  $\mu$ —as the economy becomes more efficient in production, children benefit.

$$c(t) = c_0 e^{\mu t} \quad (27)$$

The simplest specification<sup>20</sup> for adult transfer payments is to assume that adults share the burden of supporting children equally, i.e.

$$j(s, t) = j(t) \quad (28)$$

where  $j(s, t)$  is the payment that an individual adult, who became an adult at time  $s$ , is liable for at time  $t$ . Note that transfer payments are bound by the following budget constraint, which constrains aggregate child receipts to equal aggregate adult payments:

$$c(t)M(t) = \int_{-\infty}^t j(t)n(s, t) ds \quad (29)$$

Thus:

$$j(t) = \frac{c(t)M(t)}{\int_{-\infty}^t n(s, t) ds} \quad (30)$$

$$j(t) = c(t)\delta(t) \quad (31)$$

Aggregate consumption for the whole economy, then, is the sum of aggregate adult consumption and aggregate child consumption:

$$C(t) = (\theta + p)[A(t) + H(t)] + c(t)M(t) \quad (32)$$

### Income and Human Wealth

In the presentation above, individual human wealth was defined as the expected present-value of future income over an adult's remaining lifetime. Having defined the profile of labor supply over the lifecycle, we can now be more explicit with respect to income. An adult's income is after-tax labor income plus government transfers, less lump sum taxes and intergenerational transfers:

$$y(s, t) = [1 - \tau(t)]w(t)l(s, t) + tr(t) - tx(t) - j(t) \quad (33)$$

where  $y(s, t)$  denotes the income, at time  $t$ , of an adult who matured at time  $s$ ;  $l(s, t)$  is the individual effective labor supply;  $\tau(t)$  is the marginal tax rate; and  $w(t)$  is the wage paid per unit of effective labor. We assume that the distribution of lump sum taxes,  $tx$ , and

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<sup>20</sup> Bryant and Velculescu (2001) for example make most expenses for children fall on younger adults whereas we assume that adults of all ages contribute equally.

government transfers,  $tr$ , is uniform across the population, thus the year of an individual's coming of age is not a determinant of either of these two variables.

We define aggregate adult income as:

$$Y(t) = \int_{-\infty}^t y(s,t)n(s,t) ds \quad (34)$$

Taking the time derivative of  $h(s,t)$ , after substituting in the expression for individual income, we obtain:

$$\dot{h}(s,t) = [r(t) + p]h(s,t) - [1 - \tau(t)]w(t)l(s,t) - [tr(t) - tx(t) - j(t)] \quad (35)$$

The intuition for the equation above is that as time passes, future earnings are no longer as distant in time, and should therefore be discounted by a lesser magnitude—this explains the  $(r + p)$  growth—while at the same time, some income has just been received, and thus can no longer be considered part of human wealth—this explains why the current period's income is subtracted.

We can show that the evolution of aggregate human wealth is governed by the following relationship:

$$\dot{H}(t) = r(t)H(t) - Y(t) + h(t,t)n(t,t) \quad (36)$$

The intuition behind the equation above is that aggregate human wealth changes over time as future income draws nearer, thus  $H$  grows at the rate of  $r$ ; the presence of death, and hence  $p$ , does not affect aggregate human wealth, because insurance companies redistribute the wealth of the dead. Further, in each period, people receive income, and having been received, it can no longer be considered human wealth. The last term on the right hand side represents the new human wealth that the newly matured cohort brings to the economy, each period.

Further details on the approach followed in this paper and the implications of various simplifying assumptions can be found in Bryant (2004), Bryant and McKibbin (2004), Bryant and Velculescu (2001, 2002), Bryant and others (2004), and McKibbin and Nguyen (2004).

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