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Fertility, mortality and the developed world's demographic transition

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Abstract

This study uses Fehr et al. [Fehr, H., Jokisch, S., & Kotlikoff, L. J. (2004a). The role of immigration in dealing with the developed world's demographic transition. *FinanzArchiv, 60*, 296–324; Fehr, H., Jokisch, S., & Kotlikoff, L. J. (2005). The developed world's demographic transition—the roles of capital flows, immigration, and policy. In R. Brooks & A. Razin (Eds.), *Social security reform* (pp. 11–43). Cambridge: Cambridge University Press] dynamic general equilibrium model to analyze the effects of changes in fertility and mortality on the developed world's demographic transition. The model features three regions – the U.S., Japan, and the EU-15 – and incorporates age- and time-specific fertility and mortality rates, detailed fiscal institutions, and international capital mobility, subject to adjustment costs. The model's life-cycle agents maximize expected utility taking into account the uncertainty of their dates of death. Since there is no altruism, bequests arise solely as a result of incomplete annuitization. The model fits the developed world's demographic, fiscal, and economic initial conditions quite closely.

Our simulations show that, all else equal, higher fertility and lower mortality will, respectively, improve and worsen fiscal and economic conditions along the world's dynamic transition path. But we find that such demographic changes, even when very large in size and relatively quick in nature, would come too late to materially alter the fiscal and economic picture over most of this Century. Indeed, our simulations indicate only minor effects on the developed world's rather bleak baseline transition path prior to roughly 2070 arising from either major increases in fertility rates or major reductions in mortality rates. Although such changes

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have important long-run fiscal and economic effects, they occur too gradually to materially alter the short- and medium-term outcomes.

JEL classification: E2; H2; J1

Keywords: Multi-country; Overlapping generations model; Demographic transition

1. Introduction

Fertility rates in much of the developed world and some parts of the developing world, notably China, are remarkably low and have been so for decades. In Italy the rate fertility rate is only 1.2. In Germany and Japan it is just 1.3.[1] Absent sufficient immigration, fertility rates this low spell one and only one thing—depopulation. And immigration has not been high in Japan and Europe to prevent this from happening. Indeed, Japan's population is now shrinking, and Europe's will begin shrinking in just 4 years. Both economies are already seeing a decline in their work forces.

The populations of Japan and Europe are slated to decline by 30 million and 80 million, respectively, by mid Century. In contrast, the U.S., whose population is rising thanks to a 2.1 percent fertility rate and a high rate of immigration, will add 100 million Americans over the same period.

The striking low fertility rates in the EU and Japan and their implications for population implosion are hard to believe. They are even harder to accept as permanent. This explains why the OECD, the United Nations (see UNPD, 2003), and individual governments foresee, albeit with little justification, major fertility rebounds in the near term.

The relatively high U.S. fertility rate will not only help keep the U.S. population growing, it will also keep the U.S. relatively young—young that is compared to its trading partners. Compared to its past, the U.S. is slated to get quite old. By mid Century, 21 percent of Americans will be 65 or older. In Germany, the figure will be 31 percent; in Japan, it will be 37 percent. The current elderly shares in these countries are 13 percent, 17 percent, and 18 percent, respectively.

The source of this projected aging is, in part, the baby bust that followed the baby boom and, in part, the dramatic rise in life expectancy. Japanese life expectancy at birth is now 30 percent higher than it was in 1950. By 2050 it will be almost 40 percent higher. The U.S. and European gains in life expectancy are smaller, but still very impressive. By mid-century roughly half of all Japanese and Europeans will be older than 50 and half of Americans will be older than 42.

The projected rise in dependency rates portends major increases in payroll and other tax rates. This paper explores the roles of fertility and mortality in altering fiscal and economic performance over the short, medium, and long runs. This paper's goal is understanding whether alternative fertility or mortality rates could significantly alter the pending old-age fiscal crisis.

Whatever is the answer to this question, one thing is sure—many countries are now and have long been actively engaged in trying to influence both fertility decisions and mortality outcomes. China's oft-draconian one-child policy, India's past compulsory sterilization policies, Sweden's provision of full day care services, and France's generous child tax deductions and child tax

[1] For these and other demographic statistics cited see UNPD (2003).

allowances are all examples of policies designed to produce either lower or higher birth rates. The most recent example of fertility policy is Russia's President Putin's offer to pay each Russian women close to $10,000 for having a second child.[2] This is a huge sum given that per capital income in Russia is less than $4000.

Longevity is also subject to government policymaking. The U.S. government and the governments of other developed countries have been spending every larger sums on biomedical research and healthcare aimed not just at reducing morbidity, but also at limiting mortality and, thus, increasing longevity. As a result of this research and the implementation of its findings, there have been important gains in the fight against cancer, AIDs, heart disease, and other life-threatening conditions.

Much of the recent longevity improvements are arising due to improvements in survival after age 65. Today's demographers are engaged in an intense debate about the future course of longevity. Some think it will continue to rise, while others think it will reach a natural limit, see Oeppen and Vaupel (2002). The United Nations projections take an intermediate position. They assume that life expectancy will rise through 2050, but at half the rate experienced over the second half of the 20th Century.

Our focus here is not on the efficacy of government policies geared to changing fertility and mortality outcomes. Rather our focus is on the economic and fiscal effects of such policies assuming they achieve their demographic objectives. Specifically, we seek to understand whether immediate and major changes in fertility and mortality rates relative to those now projected by the United Nations will greatly alter the course of payroll and other tax rates in the developed world and China arising from the aging of these societies.

What will happen, for example, if, the UN is wrong and the fertility gap between the U.S., on the one hand, and Europe and Japan, on the other, continues unabated throughout much of this century? How would this affect tax rates, growth rates, trade flows, and income distribution in the world economy? Alternatively, what would happen were life expectancy to remain at current levels or even fall in the future? How would this affect the government budget and the social security system?

Theory alone provides no clear answers. Take a rise in fertility rates. Such a change increases the number of future tax payers and, thereby, generates more future revenues. But it also increases public education and health expenditures and other child-specific government outlays. Since fiscal systems and conditions are quite different across countries, it is not clear whether the short-run fiscal costs of more children exceed, equal, or fall short of the long-run fiscal benefits. Nor is there a definitive empirical answer to this question.

Indeed, previous research on the fiscal and economic effects of fertility changes is quite limited and yields controversial results. Cutler, Poterba, Sheiner, and Summers (1990), Guest and McDonald (2002), and Guest (2006) argue that declining birth rates have a positive economic impact on future living standards. Similarly, Heijdra and Ligthart (2006) find that a drop in the fertility rate decreases the per capita capital stock and increases per capita consumption. In contrast, Berkel, Börsch-Supan, Ludwig, and Winter (2004) suggest that higher fertility rates would improve the long-run pension finances in Germany and Hondroyiannis and Papapetrou (2005) find a positive relationship between fertility and real growth in per GDP.

Turning to changes in mortality rates, we know that increased longevity spells higher total benefit payments to current and future elderly. As Lee and Skinner (1999) stress, this implies

[2] http://www.cbsnews.com/stories/2006/05/19/world/main1635851.shtml.

a higher fiscal burden and, generally speaking, less saving and capital formation. But lifespan extension should also lead people to save more for their longer projected retirements. Bloom, Canning, and Graham (2003) provide empirical support for this view. On the other hand, Skinner (1985) argues that rising longevity will reduce savings if bequests are purely altruistic and annuity markets are incomplete.

Our simulations confirm that higher fertility and lower mortality will, respectively, improve and worsen fiscal and economic conditions along the world's dynamic transition path. But the simulations show that such changes, even were they very large in size and very quick to materialize, would come too late to materially alter the fiscal and economic picture over most of this Century. Indeed, our simulations, show major long-run effects, but small short- and medium-run effects arising from either major increases in fertility rates or major reductions in mortality rates. The explanation is simply that it takes a long-time for even big changes in fertility and mortality rates to work their effects on the economy.

The framework for our analysis is an updated version of the three-region dynamic life-cycle simulation model developed in Fehr, Jokisch, and Kotlikoff (2004a, 2005). In the following sections we proceed by discussing the model's structure, detailing its calibration, presenting its baseline simulation, and then assessing the effects of deviations from baseline fertility and mortality rates on the macroeconomic developments of the three regions.

2. The structure of the world economy

The simulation model described in this section extends Auerbach and Kotlikoff (1987) overlapping generation (OLG) model by considering population aging in a multi-regional setting. Various recent studies have analyzed the macroeconomic impact of aging in a similar framework. For example, Kenc and Sayan (2001), compare the impact of the demographic transition in Turkey on real economic variables with and without transmission effects from the main EU trading partners. They conclude that small economies with a similar trade and population structure such as Turkey could benefit from the lag between their own demographic transition and that in the lager economies in the OECD/EU area. Börsch-Supan, Ludwig, and Winter (2006) develop a multi-region model consisting of seven world regions: France, Germany, Italy, rest EU, U.S. and Canada, rest OECD, and rest of world (ROW). They simulate alternative pension reform scenarios and compare their effects for alternative capital mobility scenarios. Their analysis shows that open economies are able to diversify the demographic effects that depress savings and the rate of return to capital. Compared to the latter study, the present model consists only of three regions – the U.S., Japan, and the EU-15 – with a country specific demographic transition and international capital mobility subject to adjustment costs. However, in contrast to Börsch-Supan et al. (2006) the present study features the national fiscal institutions in detail and includes a more realistic intergenerational wealth transmission process. The model's life-cycle agents maximize expected utility taking into account the uncertainty of their dates of death. The inclusion of lifespan uncertainty permits a realistic modeling of bequests and inheritances. We generate bequests by assuming, realistically, that agents fail to annuitize their assets in old age. Hence, when they die, they leave undesired bequests to their children. Since agents die at different ages and have children of different ages, their heirs also inherit at different ages. Older heirs who were born when their parents were young receive inheritances later in their life than do their younger siblings. Finally, uninsurable lifespan uncertainty also leads to a gradual decline in consumption in old age. This is another important feature of actual longitudinal age-consumption profiles. A final key feature of our framework and an extension of Börsch-Supan et al. (2006)

is its intra-cohort disaggregation. As in Kotlikoff, Smetters, and Walliser (2007), we distinguish three income classes within each generation each with its own earnings ability. The following sections present the general structure of our model. A more detailed description is provided in Fehr, Jokisch, and Kotlikoff (2004b).

2.1. Demographics

Each region is populated by households who live at most to age 90. Consequently, there are 91 generations with surviving members at any point in time. Between ages 0 and 20 our agents are children who earn no money and are supported by their parents. At age 21 our agents leave their parents and go to work. Between ages 23 and 45 our agents give birth to fractions of children at the beginning of each period, that leave their parents at age 21. After retirement, our agents die between ages 68 and 90, so that children always outlive their parents and parents always outlive grandparents. In each year new immigrants in each skill and age group arrive with the same number and age distribution of children and the same level of assets as natives of the identical skill and age. Since the demographic structure has the same form in all three regions, it suffices to discuss a representative region and omit region indices.

To determine the evolution of the population in each region over time, we applied region- and age-specific mortality $[d(a, i)]$ and birth rates to the cohorts alive in year 2000 as well as to their children as they reach their ages of fertility and mortality. In the baseline path the exogenous current and future mortality and fertility rates follow the medium variant of the United Nations population projections (UNPD, 2003). Consequently, mortality is decreasing in all three regions until 2050, but the Japanese have a significantly higher life expectancy than do Americans or EU citizens. Total fertility rates currently equal 2.1, 1.3, and 1.5 in the U.S., Japan, and the EU, respectively. Nevertheless the United Nations expects fertility rates in all three regions to converge to 1.85 children by 2050. In the baseline path, we assume annual net immigration of 1 million per year in the U.S., 450,000 in the EU, and 54,000 in Japan. Given the population age structure in year 2000 as well as projected future fertility, mortality, and net immigration rates, we compute the population vector $N(a, t, s, k)$ for the years t between 2001 and 2050. After year 2050, fertility rates are endogenously adjusted in order to achieve zero population growth and a stable population age structure. Since net immigration is positive, the required fertility rates are below 2.0.

Fig. 1 reports the resulting changes in the total population of the three regions. Due to high fertility and net immigration rates, the U.S. population is projected to increase from 275 million in 2000 to 442 million in 2100. In Europe, the population falls over the century from 375 to 340 million. And in Japan, the population falls from 126 million to just 85 million! Fig. 2 shows our baseline projections of the dependency ratios. As one would expect, the latter are increasing in all three regions through 2050. However, the three regions experience important differences in the aging of their populations. First, the increase in the dependency ratio is much greater in Japan and Europe than in the U.S. Second, dependency ratios fall in Europe and Japan after peaking in year 2050, while they remain roughly stable after 2030 in the U.S.

In our simulations we will assume that fertility and mortality remains constant in all countries at the current levels through 2050. Constant fertility implies for the U.S. that the population will increase to 505 million by 2100, while in the EU and Japan the respective populations fall to 268 million and 60 million in 2100. Under these scenarios, dependency ratios would fall relative to the baseline in the U.S. and increase relative to the baseline in Europe and Japan. However, it takes quite a while for changes in fertility rates to materially alter dependency ratios.

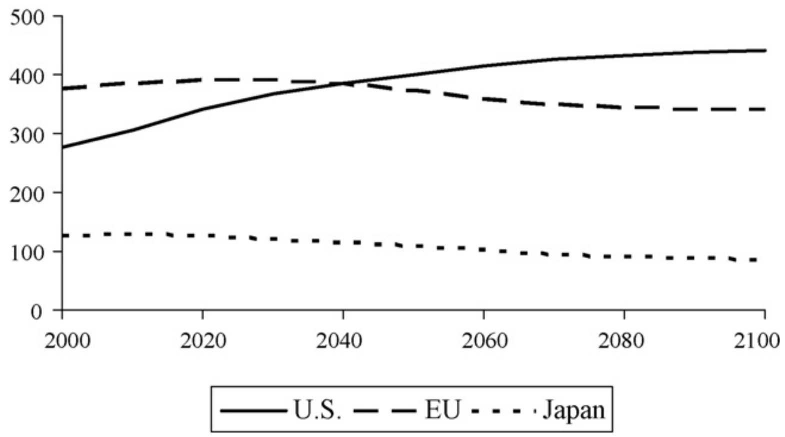

Fig. 1. Population (in million) in the baseline path.

In contrast to the effects of fixing fertility rates for a half century, fixing mortality rates at their current values reduces the future populations and the dependency ratios in all three regions. However, the effects are much smaller compared to those arising from stabilizing fertility rates.

2.2. *The household sector*

We do not distinguish between natives and immigrants once the immigrants have joined the native earnings- and age-specific cohorts. The model's preference structure is represented by a time-separable, nested, CES utility function. Remaining lifetime utility $U(j, t, s, k)$ of a generation of age j at time t whose parents were age s at time of birth and who belongs to income class k takes the form

$$U(j, t, s, k) = V(j, t, s, k) + H(j, t, s, k), \tag{1}$$

where $V(j, t, s, k)$ records the agent's utility from her/his own goods and leisure consumption and $H(j, t, s, k)$ denotes the agent's utility from the consumption of her/his children. The two

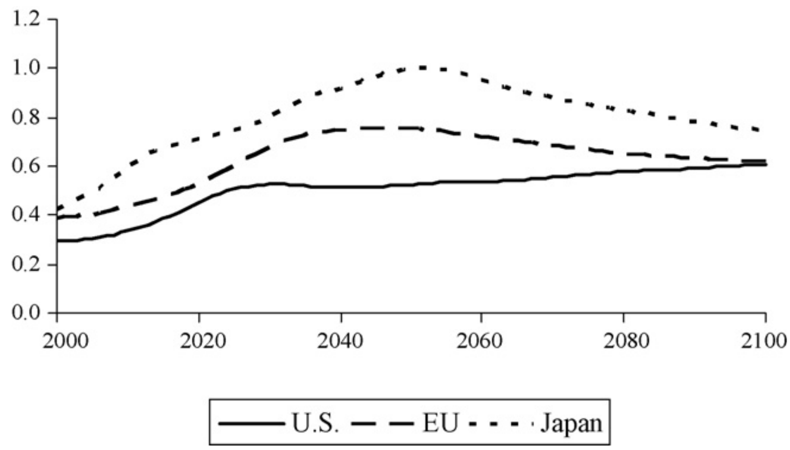

Fig. 2. Dependency ratios (65+/20–64) in the baseline path.

sub-utility functions are defined as follows:

$$V(j,t,s,k) = \frac{1}{1-(1/\gamma)}\sum_{a=j}^{90}\left(\frac{1}{1+\theta}\right)^{a-j} P(a,i) \times \left[c(a,i,s,k)^{1-(1/\rho)} + \alpha\ell(a,i,s,k)^{1-(1/\rho)}\right]^{(1-(1/r))/(1-(1/\rho))} \tag{2a}$$

$$H(j,t,s,k) = \frac{1}{1-(1/\gamma)}\sum_{a=j}^{90}\left(\frac{1}{1+\theta}\right)^{a-j} P(a,i)\mathrm{KID}(a,\ i,\ k)c_K(a.i,s,k)^{1-(1/\gamma)}, \tag{2b}$$

where $c(a, i, s, k)$ and $\ell(a, i, s, k)$ denote consumption and leisure, respectively, and i is defined as $i = t + a - j$. The children's consumption of income class k parents who are age a in period i and whose parents were age s at the time of their birth is defined as $c_K(a, i, s, k)$. The KID(a, i, k) function sums the total number of kids of the respective parent-income class generation k and divides it by the total number of parents of age a in year t who belong to income class k. This function takes into account that the family's age structure will change over time due to changing fertility. This approach permits the distribution of births by the age of parents to change over time—an important improvement relative to the birthing process stipulated in Kotlikoff et al. (2007). Since lifespan is uncertain, the utility of consumption in future periods is weighted by the survival probability of reaching age a in year i

$$P(a,i) = \prod_{u=j}^{a}[1-d(u,u-a+i)], \tag{3}$$

which is determined by multiplying the conditional survival probabilities from year t (when the agent's age is j) up to year i. Note that $d(j, t)$ is the mortality probability of an agent age j in year t. The parameters θ, ρ, α and γ represent the "pure" rate of time preference, the intratemporal elasticity of substitution between consumption and leisure at each age a, the leisure preference parameter, and the intertemporal elasticity of substitution between consumption and leisure in different years, respectively. Given the asset endowment $a(j, t, s, k)$ of the agent in year t, maximization of (1) is subject to a lifetime budget constraint defined by the sequence:

$$a(j+1,t+1,s,k) = [a(j,t,s,k)+I(j,t,s,k)](1+r(t)) + w(t)E(a,k)[h(a,t) - \ell(a,t,s,k)] - T(j,t,s,k) - c(j,t,s,k) - \mathrm{KID}(j,t,k)c_K(j,t,s,k), \tag{4}$$

where $r(t)$ is the pre-tax return on savings and $I(j, t, s, k)$ denotes the inheritance the agent receives in year t. When the parents die between age 68 and 90, their remaining assets are split between their children. Consequently, inheritances of agents who are age j in year t and whose parents were age s at their birth are defined as follows:

$$I(j,t,s,k) = \frac{d(j+s)\overline{A}(j+s,t,k)}{\sum_{u=23}^{45} N(j+s-u,t,u,k)} \tag{5}$$

The numerator defines the aggregate assets of income class k parents who die in year t at age $j + s$. The denominator defines these parents' total number of children who are between ages $j + s - 45$ and $j + s - 23$ in year t. The receipt of inheritances requires us to distinguish members of each cohort according to the ages of their parents at birth. The parents' ages at death determine when the children receive their inheritances. While the oldest children (born when their parents are age 23) receive their inheritances between ages 45 and 67, the youngest children (born when their parents are age 45) receive their inheritances earlier in life, between ages 23 and 45.

As in Altig, Auerbach, Kotlikoff, Smetters, and Walliser (2001) and Kotlikoff et al. (2007), we assume that technical progress causes the time endowment $h(a, i)$ of each successive generation to grow at the rate λ, i.e.

$$h(a, i) = (1 + \lambda)h(a, i - 1). \tag{6}$$

Gross labor income of the agent in year t is derived as the product of her/his labor supply and her/his wage rate. The latter is the product of the gross wage rate $w(t)$ in period t and the age- and class-specific earnings ability.

$$E(a, k) = \xi(k)\,\mathrm{e}^{4.47+0.033(a-20)-0.00067(a-20)^2}(1 + \lambda)^{a-21} \quad \text{with } \xi(1) = 0.2,$$
$$\xi(2) = 1.0, \quad \xi(3) = 5.0. \tag{7}$$

The middle-income class profile is taken from Auerbach and Kotlikoff (1987, 52). The shift parameters $\xi(k)$ are then applied to derive income class-specific profiles. Moreover, since technological change is an important determinant of secular growth over the life cycle, we multiply the age-specific longitudinal earnings ability profile by the term involving λ. Hence, the longitudinal age-wage profile is steeper the greater is the rate of technological change.

The net taxes $T(j, t, s, k)$ of an agent in year t consist of consumption, capital income, and progressive wage taxes as well as social security contributions net of pensions received. Due to our assumed ceiling on payroll tax contributions, pension, disability insurance and health care contribution rates differ across agents. Each agent's pension benefits depend on her/his pre-retirement earnings history, while health care and disability transfers are provided on a per capita basis to all eligible age groups.

Given individual consumption, leisure, and asset levels of all agents, we can compute the aggregate variables. For example, the aggregate value of assets $A(t+1)$ in period t is computed from

$$A(t + 1) = \sum_{k=1}^{3}\sum_{a=21}^{90}\underbrace{\sum_{s=23}^{45} a(a + 1, t + 1, s, k)N(a, t, s, k)}_{\overline{A}(a+1,t+1,k)}. \tag{8}$$

Since households die at the beginning of each period, we have to aggregate across all agents who lived in the previous period in order to compute $\overline{A}(a + 1, t + 1, k)$, which we need for the calculation of bequests, see (5). If we aggregate across agents who live in period $t+1$, i.e.

$$A(t + 1) = \sum_{k=1}^{3}\sum_{a=21}^{90}\sum_{s=23}^{45} a(a, t + 1, s, k)N(a, t + 1, s, k), \tag{9}$$

assets of the arriving immigrants of period $t+1$ are included. Finally, aggregate labor supply of agents in year t, $L(t)$, is computed from the individual labor supplies, i.e.

$$L(t) = \sum_{k=1}^{3}\sum_{a=21}^{90}\sum_{s=23}^{45} E(a, k)[h(a, t) - \ell(a, t, s, k)]N(a, t, s, k). \tag{10}$$

2.3. The production sector

The economy is populated by a large number of identical firms, the total number of which is normalized to unity. Aggregate output (net of depreciation) is produced using Cobb–Douglas production technology, where $K(t)$ is aggregate capital in period t, ε is capital's share in production, and ϕ is a technology parameter. Since we posit convex capital adjustment cost, the firms' marketable output in year t, $Y(t)$, is given by the difference between gross output and adjustment costs, i.e.

$$Y(t) = \phi K(t)^{\varepsilon} L(t)^{1-\varepsilon} - \frac{\psi}{2}\frac{\Delta K(t)^2}{K(t)}, \tag{11}$$

where $\Delta K(t)$ measures investment in year t. The term ψ is the adjustment cost coefficient. Larger values of ψ imply higher marginal costs of new capital goods for a given rate of investment. The installation technology is linear homogeneous and shows increasing marginal cost of investment (or, symmetrically, disinvestment): faster adjustment requires a greater than proportional rise in adjustment costs.

With respect to corporate taxes, $T^k(t)$, we assume that adjustment costs are fully and investment expenditures are partly deductible from the tax base. Consequently, arbitrage between new and existing capital implies that the latter has a price per unit, $q(t)$, which capitalizes the investment incentives of the tax system. Similarly, the arbitrage condition arising from profit maximization requires identical returns to financial and real investments.

2.4. The government sector

The consolidated government issues new debt $\Delta B(t)$ and collects corporate taxes and net-taxes from households in order to finance general government expenditures $G(t)$ as well as interest payments on its debt:

$$\Delta B(t) + T^k(t) + \sum_{k=1}^{3}\sum_{a=21}^{90}\sum_{s=23}^{45} T(a,t,s,k)N(a,t,s,k) = G(t) + r(t)B(t). \tag{12}$$

With respect to public debt, we assume that the government maintains an exogenously fixed ratio of debt to output. The progressivity of the wage tax system is modelled as in Auerbach and Kotlikoff (1987). Specifically, marginal wage tax rates rise linearly with the tax base.

PY(t) defines the aggregate payroll tax base, which differs from total labor earnings due to the ceiling on taxable wages. This ceiling is fixed at 250 (200, 168) percent of average income in the U.S. (EU, Japan). Aggregate average social security payroll tax rates $\hat{\tau}^p$, $\hat{\tau}^h$ and $\hat{\tau}^d$ are computed each period from the relevant budget constraint for the program and region in question. For the U.S., we determine the separate values of payroll tax rates for the Social Security pension system, Medicare, and the Social Security disability insurance systems, i.e.

$$\hat{\tau}^p(t)\mathrm{PY}(t) = \mathrm{PB}(t), \qquad \hat{\tau}^h(t)\mathrm{PY}(t) = \mathrm{HB}(t), \quad \text{and} \quad \hat{\tau}^d(t)\mathrm{PY}(t) = \mathrm{DB}(t), \tag{13}$$

where PB(t), HB(t) and DB(t) are total outlays of the pension, health care, and disability systems, respectively. In the EU and Japan, disability insurance is part of their respective state pension systems. Hence, we do not calculate separate disability insurance payroll tax rates for those regions.

Due to contribution ceilings, individual pension and health insurance payroll tax rates can differ from the payroll tax rate. Above the contribution ceiling, marginal social security contributions are zero and average social security contributions fall with the agent's income. To accommodate this non-convexity of the budget constraint, we assume that the highest earnings class in each region pays pension and in the EU and Japan health insurance payroll taxes, up to the relevant ceilings, but faces no pension and no health care payroll taxes at the margin. The other earnings classes are assumed to face the full statutory rate on all earnings. In the U.S., the disability payroll tax is modelled in an equivalent manner. However, since there is no ceiling on U.S. Medicare taxes, all earnings groups are assumed to face the health insurance payroll tax at the margin. If a k-income class agent, whose parents were s years old at his birth, retires in year z at the exogenously set retirement age $\bar{a}(z)$, her/his pension benefits $\text{Pen}(a, i, s, k)$ in years $i=z$ when she/he is age $a = \bar{a}(z)$ depend linearly on her/his average earnings during his working time

$$\text{Pen}(a, i, s, k) = \omega_0 + \omega_1 \bar{W}(z, s, k). \qquad (14)$$

The region-specific parameters ω_0, ω_1 were chosen in order to approximate the replacement rates relative to individual lifetime earnings as reported in Whitehouse (2002).

General government expenditures $G(t)$ consist of government purchases of goods and services, including educational expenditures and health outlays. Over the transition, government purchases of goods and services are held fixed per capita with an adjustment for annual technological change. Age-specific education, health, and disability outlays are also held fixed over the transition with the same adjustment for technological change. The government's budget (12) is balanced each year by adjusting the intercept on our linear formula for the average wage tax rate.

2.5. World equilibrium

Up to now we have described the model for the representative economy. The three regions of the model are connected through the world capital market. Consequently, the aggregate value of world assets equals the market value of the world-wide capital stock plus the value of all outstanding regional government bonds:

$$\sum_{x \in W} A(t, x) = \sum_{x \in W} [q(t, x)K(t, x) + B(t, x)], \quad \text{with } W = \{\text{U.S., EU, Japan}\}. \qquad (15)$$

3. Calibration and initial world equilibrium

To solve the model we specify the preference, technology, and policy parameters as reported in Table 1.

The choice of our preference and technology parameters is discussed in Fehr et al. (2004b). In calibrating our model, we use Japanese age-specific government health care expenditure profiles for Japan. In the case of the EU, we use the German profile. For the U.S., the Medicare program applies only to households older than 65. We assume uniform Medicare expenditures by age among those over age 65. We make the same uniform age-distribution assumption with respect to the U.S. disability insurance system, which we assume applies only to those older than 20 and younger than 65. We use the German age-specific education profile for all regions in the model and rescale it to get realistic education outlays in year 2000 in each region (see below). In addition to these parameter values, our model requires an initial distribution of assets by age and income class for each region.

Table 1
Parameter values of the model

	Symbol	Value		
		U.S.	EU	Japan
Utility function				
Time preference rate	θ		.02	
Intertemporal elasticity of substitution	γ		.25	
Intratemporal elasticity of substitution	ρ		.4	
Leisure preference parameter	α		1.5	
Production function				
Technology level	ϕ	1.041	1.048	1.049
Capital share in production	ε		.25	
Adjustment cost parameter	ψ		10.0	
Technical progress			.01	
Policy parameters				
Consumption tax rate (in %)	τ^c	11.3	19.5	13.0
Capital tax rate (in %)	τ^r	11.4	13.3	10.0
Corporate tax rate (in %)	τ^k	10.0	13.3	15.0
Expensing fraction (in %)		20.0	20	30.0
Debt (in % of national income)	B/Y	40	50	48
Age of retirement	$\bar{a}(z)$	63	60	60
Portfolio shares				
Capital share in the U.S. (in %)		95.8	3.4	.8
Capital share in the EU (in %)		2.0	97.8	.2
Capital share in Japan (in %)		.7	.8	98.5

These profiles are region-specific and computed from the data reported in Kraay et al. (2005).

Table 2 reports key macroeconomic variables in 2000 in the three regions. Note that there is a fairly close accordance between actual and computed national income account measures of private consumption and government purchases. The one exception is Japanese government purchases. The official data seem too high given the reported ratio of tax revenues to national income. In our calibration, we chose to benchmark government purchases based on the ratio of tax revenues to national income. The reported shares in education, pensions and health are very close to actual levels. The same applies to the social security payroll tax rates and the level and progressivity of the three income taxes. Concerning the overall structure of tax revenues, the assumed tax rates on capital income, corporate income and consumption as well as the expensing fractions (see Table 1) yield a realistic pattern. Finally, the model's year-2000 capital–output ratios seem reasonable not only relative to U.S. Commerce Department figures, but also in terms of the year-2000 interest rate, which equals 8.1 percent. As discussed in Fehr et al. (2004a), calibrating the model to a lower initial capital–output ratio will alter the extent to which simulated capital–labor ratios decline and real wages fall over the developed world's transition path.

Now we turn to the simulation results for the baseline transition where, to repeat, we incorporate the medium variant of the United Nations population projections. The transition paths for the three regions are reported in Table 3 for the U.S., EU and Japan.

Although the economies are aging, the baseline path shows a steadily increase in effective labor supply in all three regions. This may seem surprising especially for Japan and the EU where the population and work force decline over time (see Fig. 1). The explanation lies in our assumed

Table 2
The year 2000 of the baseline path[a]

	Model			Official[b]		
	U.S.	EU	Japan	U.S.	EU	Japan
National income						
Private consumption	78.2	70.3	73.1	77.6	67.8	67.8
Government purchases of goods and services	22.9	32.6	22.3	23.0	32.1	33.4
Current account	−1.3	−.8	5.2	−4.6	−.4	3.0
Government indicators						
Aggregate education outlays	5.9	6.0	4.2	5.9	6.0	4.3
Aggregate pension benefits	6.2	11.5	10.8	5.7	11.6	10.8
Aggregate health benefits	2.2	6.3	5.2	2.5	6.2	6.8
Aggregate disability benefits	1.3	–	–	.9	–	–
Pension contribution rate (in %)	8.9	17.1	16.7	10.6	–	17.3
Health care contribution rate (in %)	2.9	9.4	8.0	2.9	–	8.0
Disability insurance contribution rate (in %)	1.9	–	–	1.9	–	–
Tax revenues	21.9	29.8	20.7	26.6	32.5	20.7
Direct taxes	13.1	16.1	11.2	17.9	16.5	10.5
Personal income taxes	10.6	12.7	7.4	14.7	12.8	6.2
Wage taxes	7.4	9.0	4.9	–	–	–
Capital taxes	3.2	3.7	2.5	–	–	–
Corporate income taxes	2.5	3.4	3.8	3.2	3.7	4.3
Indirect taxes	8.8	13.7	9.5	8.7	16.0	10.2
Wage tax rates (in %)						
Average	10.2	12.1	6.6	–	–	–
Marginal	17.2	18.2	12.1	–	–	–
Capital–output ratio	3.2	3.2	2.8	–	–	–
Interest rate (in %)		8.1		–	–	–

[a] In percent of national income if not stated differently.
[b] European Commission (2003).

rate of labor-augmenting technological change permitting greater effective labor supply by each successive cohort. Thus, the future decrease in the labor force is offset in the EU and Japan and the growth in the actual number of workers in the U.S. is augmented. However, effective labor supply grows at much different rates in the three regions. In Japan it increases by 63 percent over the century. In the EU it more than doubles over the same period. And in the U.S. it increases over the century by a factor of four. The differences in effective labor supply growth across the three regions materially affect overall economic growth. In the U.S. output grows by a factor of 3.6 over the next 100 years. It grows by a factor of 2.2 in the EU and 1.4 in Japan.

A second key feature of our base-case simulation is the emergence over time of a significant capital shortage. Although the overall capital stock doubles in the U.S. over the century, capital per unit of human capital declines. This development is even more dramatic in the EU and Japan where the capital stocks fall during the transition. The observed capital shortages lower real wages per unit of human capital by 16 percent in Japan and by almost 20 percent in the U.S. and the EU over the course of the century. The associated increase in the real interest rate over this period is 390 basis points. This major crowding out of capital can be explained by the increases in the payroll and wage tax rates, which are reported in the last two columns of the charts.

Over the century, combined social security payroll tax and wage tax rates rise by 77 percent in the U.S., by 64 percent in the EU, and by 79 percent in Japan. By 2100, the combined payroll

Table 3
Simulation results for the baseline path

Year	Index of national income	Index of capital stock	Index of labor supply	Current account/NI	Index of pre-tax wage	Capital price	Interest rate	Social security cost rate	Average wage tax	Bequest/NI
U.S.										
2000	1.00	1.00	1.00	−.013	1.00	1.000	.081	.137	.102	.026
2005	1.10	1.01	1.13	−.014	.97	1.044	.084	.140	.107	.023
2010	1.21	1.03	1.28	−.012	.95	1.074	.084	.150	.110	.022
2020	1.44	1.12	1.57	−.017	.92	1.098	.084	.191	.122	.024
2030	1.68	1.21	1.88	−.007	.90	1.071	.092	.226	.134	.029
2050	2.17	1.35	2.55	.028	.85	1.064	.110	.236	.149	.021
2075	2.81	1.59	3.41	.019	.83	1.094	.119	.264	.145	.027
2100	3.62	2.01	4.43	.005	.82	1.105	.120	.280	.144	.033
EU										
2000	1.00	1.00	1.00	−.008	1.00	1.000	.081	.265	.121	.019
2005	1.07	.98	1.10	−.006	.97	1.038	.084	.273	.125	.018
2010	1.13	.97	1.19	−.002	.95	1.061	.084	.288	.129	.020
2020	1.23	.97	1.33	.008	.93	1.069	.084	.333	.143	.025
2030	1.27	.96	1.39	−.003	.91	1.032	.092	.413	.172	.027
2050	1.41	.90	1.63	−.028	.86	1.058	.110	.446	.215	.024
2075	1.73	.97	2.10	−.021	.82	1.127	.119	.404	.244	.017
2100	2.21	1.19	2.73	−.008	.81	1.154	.120	.385	.250	.011
Japan										
2000	1.00	1.00	1.00	.052	1.00	1.000	.081	.247	.066	.020
2005	1.03	1.00	1.04	.050	.99	1.006	.084	.279	.066	.021
2010	1.04	.99	1.06	.036	.98	1.007	.084	.324	.068	.024
2020	1.07	.99	1.10	.022	.97	.998	.084	.379	.074	.026
2030	1.07	.95	1.12	.035	.96	.949	.092	.427	.086	.025
2050	1.03	.81	1.12	−.014	.92	.955	.110	.532	.106	.016
2075	1.17	.78	1.33	−.005	.88	1.035	.119	.457	.126	.020
2100	1.40	.89	1.63	.008	.86	1.074	.120	.425	.137	.015

plus average wage tax rate equals 42.4 percent in the U.S., 63.5 percent in the EU, and 56.2 percent in Japan. These very high rates of taxation reduce the ability of workers to save and, therefore, accumulate claims to physical capital. Table 3 also shows that the different timing of the aging process in the three regions induces major capital flows. Since aging is much more severe in Europe and Japan, the U.S. experiences capital inflows from these regions throughout the century. Consequently, the initial U.S. current account deficit of 1.3 percent of national income improves rather slowly and finally turns into a surplus in the second half of the century. The opposite happens in the capital exporting countries. In the EU, the initial current account deficit improves but returns to a deficit again after 2040. In Japan the initial current account surplus of 5.2 percent declines steadily until the aging process peaks in the second half of the century. Despite the aging process, asset prices increase in the U.S. and in Europe, but they fall temporarily in Japan below their initial values. The latter outcome supports the widely held belief that aging will lower worldwide capital prices as the growing number of elderly start to sell their assets. Our simulations suggest that this effect will only be significant in Japan, although asset prices are also dampened in the other countries.

The final columns report the development of bequests (relative to national income (NI)) during the transition. While many people believe that bequests will rise significantly during the aging process, our results belie this view. This perhaps surprising result is mainly due to the increase in life expectancy during the transition. Reductions in mortality rates reduce the levels of unintended bequests left to children.

4. The impact of fertility changes

This section considers what happens if fertility rates remain at their current levels through 2050. Since in the baseline path fertility rates fall in the U.S. and increase in the EU and in Japan, constant birth rates imply (compared to the baseline path) lower population growth in the EU and in Japan and higher population growth in the U.S. compared with the baseline paths (see the discussion of Figs. 1 and 2). We analyze a scenario in which birth rates change in the U.S., the EU, and Japan simultaneously.[3] While in the U.S. the initial fertility rate of 2.11 births per woman is kept fixed, fertility in the EU and Japan remains at their current levels of 1.46 and 1.28 births per woman through 2050.[4] Table 4 shows the impact of this scenario in all three considered regions.

The higher short-term U.S. fertility rate increases that country's total population as well as its effective labor supply. The latter variable is first affected in 2022 when the first cohort generated by the higher birth rate enters the labor force. Effective labor supply in 2100 is increased by 17 percent and national income by 15 percent relative to the baseline simulation. Due to the younger population age-structure and the increased labor supply, social security contribution rates in the U.S. decrease. In 2100 the social security payroll tax is 26 percent, compared to 28 percent in the base case. However, the average wage tax rate rises. Compared with the base case results, the average wage tax rate is 1.2 percentage points higher in 2075 and .7 percentage points higher in 2100. This reflects the need to finance additional government expenditures associated with the population increase. Due to these opposite effects on after-tax wage income, the capital stock in 2100 is only 11 percent higher relative to the base case leading to a further decline in the

[3] In Fehr et al. (2004b) we also report simulations with isolated changes in fertility in each country.

[4] After 2050 fertility rates in the U.S. fall again to their long-run value of 1.8 in order to achieve a zero long-run population growth rate, while they increase in EU and Japan to 1.77 and to 1.86 births per woman, respectively.

Table 4
Simulation results for constant fertility

Year	Index of national income	Index of capital stock	Index of labor supply	Current account/NI	Index of pre-tax wage	Capital price	Interest rate	Social security cost rate	Average wage tax	Bequest/NI
U.S.										
2000	1.00	1.00	1.00	−.013	1.00	1.000	.081	.137	.102	.026
2005	1.10	1.01	1.13	−.013	.97	1.043	.084	.140	.107	.023
2010	1.21	1.03	1.28	−.010	.95	1.072	.084	.150	.110	.022
2020	1.44	1.12	1.57	−.018	.92	1.098	.085	.191	.125	.024
2030	1.69	1.21	1.90	−.013	.89	1.076	.092	.225	.139	.029
2050	2.25	1.38	2.66	.017	.85	1.079	.111	.228	.160	.020
2075	3.14	1.71	3.86	.017	.82	1.113	.121	.241	.157	.024
2100	4.17	2.23	5.18	.018	.81	1.112	.124	.260	.151	.029
EU										
2000	1.00	1.00	1.00	−.008	1.00	.998	.081	.265	.122	.019
2005	1.06	.98	1.10	−.007	.97	1.034	.084	.273	.125	.018
2010	1.13	.97	1.18	−.003	.95	1.056	.084	.289	.129	.020
2020	1.22	.96	1.32	.008	.92	1.062	.085	.334	.140	.025
2030	1.24	.94	1.37	.000	.91	1.022	.092	.417	.165	.028
2050	1.32	.85	1.52	−.020	.87	1.031	.111	.468	.200	.026
2075	1.44	.82	1.73	−.022	.83	1.079	.121	.460	.235	.023
2100	1.71	.92	2.11	−.026	.81	1.133	.124	.425	.256	.015
Japan										
2000	1.00	1.00	1.00	.052	1.00	.998	.081	.247	.066	.020
2005	1.02	.99	1.03	.050	.99	1.002	.084	.279	.066	.021
2010	1.03	.99	1.05	.035	.98	1.001	.084	.325	.068	.024
2020	1.06	.98	1.10	.024	.97	.991	.085	.381	.071	.027
2030	1.05	.93	1.10	.043	.96	.937	.092	.433	.080	.025
2050	.93	.75	1.00	−.006	.93	.917	.111	.580	.088	.018
2075	.89	.62	1.00	−.023	.89	.972	.121	.561	.109	.028
2100	.96	.61	1.11	−.034	.86	1.042	.124	.503	.142	.022

capital–labor ratio. Hence, the pre-tax wage in the medium and long run is somewhat lower than in the base case and asset prices and the interest rate are slightly increased. Note also that bequests are slightly lower in the long run. This appears due to the fact that agents save less for their old age when they have more children.

In the EU and Japan, the lower short-run fertility rates lead to smaller work forces and total populations in the EU and in Japan. In the EU, for example, labor supply and national income in 2100 are each 23 percent smaller compared to the respective baseline values. These are big differences. In Japan, the maintenance of current fertility patterns through 2050 reduces effective labor supply at the end of the century by 32 percent and national income by 31 percent. Indeed, the absolute size of the Japanese economy (as measured by national income) is smaller in 2100 than in 2000 notwithstanding 100 years of technological progress!

Since dependency ratios in both regions rise compared to the baseline path, social security tax rates increase stronger in both countries. On the other hand, average wage tax rates are slightly reduced during the early stages of the transitions since government expenditures decrease with the reduction in the sizes of the overall populations. After 2075, however, the reduction in the effective labor supply outweighs this factor and wage tax rates rise relative to the baseline paths. Consequently, households save less and export more capital to the U.S. Asset prices and the capital stock in both regions decline sharply compared to the base case. The somewhat higher capital–labor ratios during the transition increase pre-tax wages slightly.

5. The impact of changes in life expectancy

This section analyzes the economic effects of changing life expectancy in our model. As discussed in the introduction, no one knows whether longevity will continue to grow or reach a limit. Since the baseline path takes a median view with slowly decreasing mortality rates, the present section considers a situation where mortality rates either remain at their current levels or fall further than on the benchmark path. In the latter case, we assume life expectancy to increase to 85 years in the U.S. and 86.9 years in the EU until 2050 compared to 83.8 years and 84.6 years, respectively, in the baseline transition path. These values find support by the projections of Tuljapurkar, Li, and Boe (2000). For Japan we assume a rise in longevity to 91 years. This serves as a nice special case since in our model a rise in life expectancy reduces life span uncertainty so that bequest decline to zero in Japan in the long run.[5]

The upper part of Table 5 reports our simulation results when we keep the mortality in all three regions simultaneously constant. Hence, the life expectancy in the U.S. is 81.7 years, in the EU 82.2 years and in Japan 83.8 years during the whole transition path. As a consequence population aging is less severe in all three regions at the same time. However, Japan still faces the most severe aging process due to its lower fertility rates and its higher level of longevity compared to the other two regions. Nevertheless, the effects in Japan are most pronounced since in the base case the life span increases the most. Due to the smaller number of elderly, social security payroll taxes in 2030 are .9 percentage points in the EU, 2.2 percentage points in Japan and .7 percentage points in the U.S. below the corresponding values in the base case. The capital stock, the effective labor supply, and national income are lower in all three regions compared to the base case. The bequest–output ratio increases in all regions. In Japan it even more than doubles in the medium

[5] In Fehr et al. (2004b) we furthermore analyze a scenario which combines higher longevity with lower fertility in Japan.

Table 5
Simulation results for changes in mortality rates

Year	Index of national income	Index of capital stock	Index of labor supply	Current account/NI	Index of pre-tax wage	Capital price	Interest rate	Social security cost rate	Average wage tax	Bequest/NI
(A) Constant mortality rates in all regions										
U.S.										
2000	1.00	1.00	1.00	−.011	1.00	.991	.081	.137	.102	.026
2030	1.65	1.16	1.86	−.005	.89	1.060	.095	.219	.138	.033
2100	3.55	1.96	4.35	.004	.82	1.108	.120	.257	.145	.038
EU										
2000	1.00	1.00	1.00	−.008	1.00	.992	.081	.265	.122	.019
2030	1.24	.92	1.37	−.005	.90	1.020	.095	.404	.176	.030
2100	2.16	1.16	2.67	−.007	.81	1.157	.120	.359	.246	.013
Japan										
2000	1.00	1.00	.99	.048	1.00	.990	.081	.247	.066	.020
2030	1.05	.90	1.10	.035	.95	.936	.095	.405	.092	.038
2100	1.34	.85	1.57	.008	.86	1.078	.120	.381	.135	.032
(B) Higher life expectancy in all regions										
U.S.										
2000	1.00	1.00	1.00	−.016	1.00	1.007	.081	.137	.102	.026
2030	1.70	1.25	1.90	−.011	.90	1.082	.089	.229	.132	.025
2100	3.66	2.03	4.48	.006	.82	1.102	.120	.292	.144	.027
EU										
2000	1.00	1.00	1.00	−.008	1.00	1.007	.081	.265	.121	.020
2030	1.29	.99	1.40	−.002	.92	1.043	.089	.421	.168	.022
2100	2.26	1.21	2.78	−.009	.81	1.151	.120	.410	.253	.007
Japan										
2000	1.00	1.00	1.00	.058	1.00	1.008	.081	.246	.066	.020
2030	1.09	.98	1.13	.042	.96	.960	.089	.442	.082	.018
2100	1.43	.91	1.67	.005	.86	1.070	.120	.460	.136	.000

and long run showing the strong dissaving of the elderly in the baseline path. Interestingly, the short-run current account deficit in the U.S. and the surplus in Japan are lower than in the base case. This shows that more capital from the U.S. is invested in Japan. In the medium and long run, more capital flows from the EU to the U.S. while the current account in Japan is much the same as in the baseline path. Since people save less, the initial capital prices are reduced in all regions. However, in the long run the lower capital stocks push up capital prices.

The lower part of Table 5 reports the simulation results of increasing life expectancy. Greater longevity raises the need for more resources after retirement. Therefore, labor supply and the capital stock are raised in all three regions compared to the base case. The broadening of the tax base implies a slight decline in wage tax rates. However, at the same time, higher life expectancy leads to a rise in the dependency ratios to a much larger extent relative to the baseline transition path. Hence, the social security contribution rates are increased by 1.2 percentage points in the U.S., 2.5 percentage points in the EU, and 3.5 percentage points in Japan by 2100. This development hinders greater capital accumulation so that the increase in the capital stock is lower than in labor supply. Since agents now consume a bigger part of their resources by themselves, bequests are lower than in the base case. While the current account in the EU is hardly affected by this scenario, the current accounts in the U.S. and Japan change markedly. Since the aging process in the U.S. still is less severe, more capital is imported from Japan during the first 30 years of the transition. Afterwards, this effect is reversed. Due to the overall capital scarcity, capital prices in all three regions during the first decades of the transition are higher compared to the base case.

6. Conclusion

This paper applies the three-region dynamic general equilibrium life-cycle model introduced by Fehr et al. (2004a, 2005) in order to analyze the economic effects of changes in fertility and mortality. The original model was modified in several ways. The new model includes realistic exogenous portfolio shares for international investment, an improved Japanese tax structure, and corporate taxes. Despite these adjustments, our baseline transition path highlights the same quantitative implications as in our previous papers. Population aging leads to a major capital shortage during the century due to dramatically increasing payroll and wage tax rates. This is accompanied by a decline in wages of almost 20 percent and an increase in the interest rate by 390 basis points.

Due to the strong home biases of investment flows, the immediate spill-over effects of economic shocks are now small compared to our previous work. Firstly, we consider the economic impact of alternative fertility trends in the U.S., EU and Japan. Our findings suggest that in contrast to the public opinion higher fertility cannot alleviate the demographic stresses. Although a higher number of births reduces social security contribution rates in the long run, it increases general government expenditures for education, etc. in the short- and medium-run which offsets the positive effect of reduced payroll tax rates.

With respect to future trends in life expectancy, our simulations suggest that further increases in longevity have only a modest positive impact on saving rates. Although lower mortality increases the demand for resources during retirement, it also implies a further increase in the future payroll tax rates and a decline in unintended bequests, which both tend to reduce individual and aggregate savings. Due to these counterbalancing effects, capital accumulation is only modestly affected by changes in life expectancy, and the general economic impact of mortality trends is much smaller than the impact of fertility trends.

Our bottom lines are twofold: (a) there is little reason to expect future changes in fertility and/or mortality to alleviate the future demographic stresses facing the developed world, and (b) the only way to improve future economic conditions in the developed world is to engage in major and immediate fiscal adjustments.

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