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The Demographic Deficit*

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Abstract

There has been a slowdown in growth in the world's most advanced economies. In this paper we argue that changing demographics, in particular aging populations combined with increased life expectancy, may be part of the explanation for why we observe slower growth, falling interest rates and falling productivity growth. Using Japan and the U.S. in the years prior to the financial crises as a case study, we provide estimates of the growth deficit that arises from an aging cohort structure and increasing life expectancy. We also provide projections of the impact of predictable demographic changes on future growth in the U.S. and Japan.

JEL Classification Codes: E1, E2, J1, J2

Keywords: mortality, fertility, life-cycle saving, labor supply, growth accounting

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1 Introduction

How much of the slowdown in growth among the world's most advanced economies is due to demographic factors? In this paper we estimate the extent to which aging of the population, both changes in life expectancies and shifts in cohort distributions, may account for the slowdown in growth and productivity. In many economies these demographic changes are substantial. They affect both the labor supply and savings decisions of households and how these decisions are aggregated. In this paper, we identify the channels through which changes in demographics may affect aggregate economic growth, and we show that a substantial fraction of the slowdown in growth and productivity are due to demographic factors.

The recovery from the Great Recession in both the U.S. and Europe has been anemic. There are two popular accounts of why current and expected future growth rates are low. One view, articulated by Gordon (2016), holds that aggregate supply may be impaired because the opportunities for technological change that exist in the future are not going to provide the dramatic increases in productivity that important innovations in the past have delivered. That is, the set of blueprints available to us now and in the future are not as transformative as those we have had in the past.[1] An alternative view, the secular stagnation hypothesis associated with former Treasury Secretary Larry Summers, is that future growth is likely to be constrained by insufficient investment demand. On this view our current slow growth is more than just a hangover of the financial crisis. It is a consequence of the fall in the real interest rate that prevails in equilibrium. If the real interest rate is well below zero, then monetary policy is going to have a hard time delivering a real rate that is consistent with long term growth as we have experienced it in the past.[2]

The common element in these accounts is that the growth slowdown will be persistent. We do have other examples of persistent stagnation in previously fast growing economies,

[1] The more nuanced statement of this view argues that the period from 1970-1994 when total factor productivity grew at an average annual rate of 0.5% (compared to 1.89% from 1920-1970) is likely to be characteristic of the future largely because the potential for technological innovation is unlikely to offer the opportunities for the kind of big increases in productivity that we experienced in the past.

[2] See e.g. Summers (2014) and Summers (2016).

the most notable being Japan. Japan has been stagnant since the early 1990's in spite of aggressive monetary and fiscal stimulus. Similarily, in both Europe and the U.S. growth rates were below the trend in the period leading up to the financial crisis. After the crisis, the growth rates have been below that in previous recoveries from recessions despite aggressive monetary and fiscal stimulus.

The challenge is to identify factors that can account for the persistence of the slowdown. One low-frequency factor is the demographic structure of an economy. It is widely recognized that demographic changes have important implications for economic growth. But the channels through which these changes work are less well understood. In this paper we make them precise in the context of a life cycle model with rich demographics.

There is increasing recognition that demographic changes are an important driver of many economic phenomena. In the years prior to the Financial Crisis there was a lot of concern about global current account imbalances and capital flows. A number of papers recognized that changing demographics could account for much of the observed decline in real interest rates and the magnitude and persistence of cross-border capital flows. Henriksen (2005) and later Backus, Cooley, and Henriksen (2014) showed the effect of demographic changes on capital flows and interest rates in the U.S. and Japan. Feroli (2003) explored the role of demographics for capital flows among the G7 nations. Krueger and Ludwig (2007) studied the consequences of demographic changes for rates of return on capital, wages, and wealth in the OECD Countries. More recently Gagnon, Johannson, and López-Salido (2016), Carvalho, Ferrero, and Nechio (2016), and Ikeda and Saito (2014) have shown the impact of demographic changes on the real interest rate and investment in the U.S. and Japan as a consequence of the exogenous impact of these changes on the aggregate labor supply. All these papers have focused on how demographic change affects the supply of and demand for capital.

Demographic change affects factor supplies through changes in life expectancy and changes in the age-cohort distribution of the population. Changes in life expectancy impact not only individuals' life-cycle savings decisions but also their labor-supply decisions. Changes in cohort distributions affect the aggregation of these individual decisions. We distinguish analytically between these two channels of demographic change. The general equilibrium effect of demographic change is also important. The wage rate and the real rate of interest change as a results of changes in the relative supply and demand for labor and capital. The effects on aggregate factor prices may magnify or dampen the individual life-cycle decisions shaped by demographic change.

Growth accounting shows that that growth differentials both across countries and over time are not only driven by TFP and capital accumulation, but labor supply on the extensive margin, labor supply on the intensive margin, and (obviously) population growth. One straightforward way in which demographics impact changes in aggregate economic activity is through their impact on aggregate factor supply. Data show that households steadily decrease labor supply both on the intensive and extensive margin in the latter part of their working lives. This is in contrast to the usual assumption in overlapping-generations models, that households supply labor inelastically until retirement age. Changes in life expectancy and cohort distributions will therefore affect both labor market participation and average hours worked. Faced with increases in life expectancy individuals need to provide for more years in retirement during their working life. In addition, aging populations means more people will be in their highest savings years. This may lead to changes in aggregate capital supply. Lastly, demographic change affect the composition of the work force and its productivity. Changes in the average efficiency of the individuals working will manifest itself in changes in TFP.

Economists have struggled to reconcile labor supply elasticities estimated from micro-economic data and elasticities implied by macro-economic adjustments. But one key to reconciling these two is to distinguish all the margins of adjustment of labor supply.[3] The assumption common in life-cycle models that labor is supplied inelastically when individuals enter the labor market in their early 20s until they exit the labor market at retirement age is at odds with the evidence that labor supply on the extensive margin (labor-market participation) and on the intensive margin (hours worked conditional on being in the labor

[3]Keane and Rogerson (2011) and Prescott, Rogerson, and Wallenius (2009) discuss the biases in the estimates of labor supply elasticity that result from ignoring the margins of adjustment.

force) have a pronounced hump-shape over the life cycle (see e.g. Bick, Fuchs-Schündeln, and Lagakos, 2016).[4]

Measured aggregate productivity change is a measure of output change adjusted for changes in factor inputs. Due to measurement issues, labor is usually measured as number of hours worked. The efficiency of a worker, conditional on the numbers of hours worked, will on average also depend on age. In the literature estimating life-cycle income uncertainty the predictable component of wage rates has been found to be hump-shaped (see e.g. Huggett, Ventura, and Yaron, 2011). Demographic change, both through changes in labor-supply decisions and through the aggregation, will affect aggregate productivity and measured TFP.

Two papers similar in spirit to this paper are Maestas, Mullen, and Powell (2016) and Jones (2017). Maestas et al. (2016) use cross-sectional variation to estimate the effect of increases in the fraction of the population over 60 on GDP at the state level. They find that a 10% increase in the fraction of the population over 60 decreases growth by 5.5%. and that predictable changes in the age structure will lower per capita GDP growth by 1.2% annually over the current decade. Jones (2017) uses a representative-agent model to approximate a lifecycle model. The model partially accounts for lower output and productivity growth after 2009. A contrarian story is presented by Acemoglu and Restrepo (2017) who present evidence to the effect that changes in the age structure of the population (the ratio of old to young workers) are not correlated with changes in GDP per capita but are correlated with the adoption of robots and advanced information technology. A related approach is that taken by Favero and Galasso (2015) who treat this as a statistical question that can be answered by projecting mortality based trends on growth rates and interest rates. They suggest, based on their methodology, that demographic factors account for lower growth but not lower interest rates. We study the relationship between demographics and growth and interest rates through the lense of a structural general equilibrium model driven by

[4]In the U.S. two thirds of the labor market adjustment over the business cycle occur on the intensive margin, meaning that changes in employment dominate changes in hours (Cho and Cooley, 1994). Llosa, Ohanian, Raffo, and Rogerson (2012) show, in countries with employment protection laws, a large fraction of the adjustment takes place on the intensive margin.

rich demographics. This provides a sharper understanding of the margins through which demographics are driving growth and a laboratory in which to analyze potentially welfare-improving policy options.

Understanding the magnitude of the contribution of demographics to long term growth and productivity is particularly important because the demographic forces are essentially baked in to the future path of the economy. They are not easily altered or easily influenced by economic policy other than perhaps by immigration policy. But understanding the behavioral response to these economic forces at the household level is important for understanding the connection to interest rates and the corresponding connection to policy. Aging populations present a number of challenges for the social organization of societies and for health care, retirement insurance and the sustainability of public debt.[5] We don't address these issues in the paper but provide the most parsimonious framework to account for the effect of demographic change on long-run growth and a framework within which it is possible to analyze the effects of policy responses both on aggregate growth and on welfare.

[Insert Figure 1, Figure 2, and Figure 3 about here]

2 The growth and productivity slowdown

The growth and productivity slowdown is evident in trend GDP growth for a number of countries. Figure 1 shows the trend GDP for the U.S., France (as a representative of the other G7 countries), and Japan.

The downward shift in growth in Japan is evident beginning in the early 1990's while the U.S. and France show a noticeable downward shift beginning in about 2007. Figure 2 shows the 10 year Treasury Rate for Japan and the U.S.. In Japan there was a sharp decline beginning in the early 1990's and in the U.S. beginning in the 2007. This is consistent with

[5] For example Attanasio, Kitao, and Violante (2007) and Kitao (2014) study the impact of demographics on the sustainability of social security programs.

the secular stagnation view and with an unanticipated increase in life expectancy. Figure 3 shows the evolution of life expectancy for the United States, Japan, and France.

In this paper we estimate the magnitude of the contribution of demographics to these trends. The two most significant demographic trends over the past several decades have been the increases in life expectancy and in the average age. The combination of increasing life expectancy and decreasing fertility means that the median age of the population is increasing, in some cases dramatically. This pattern is most evident in Japan where the combination of low fertility and increasing life expectancy is causing the population to shrink by a million people a year and the median age to increase from 37 years to 44 years between 1990 and 2007.

Here we are concerned with the impact of these trends on economic growth. Growth accounting is a useful framework for addressing the question at hand because it makes clear the relationship between changes in factor inputs and measured total factor productivity. Consider the standard neoclassical production function:

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

where Y is output, K is the capital stock, L is employment (the extensive margin of labor supply), and h is average hours conditional on being in the labor force (the intensive margin of labor supply). Dividing through by population, Pop, we can write this as

$$Y_t = A_t \cdot \left(\frac{K_t}{L_t}\right)^{\alpha} \cdot Pop_t \cdot \frac{L_t}{Pop_t} \cdot h_t^{1-\alpha} \tag{2}$$

and

$$A_t = \frac{Y_t}{\left(\frac{K_t}{L_t}\right)^{\alpha} \cdot L_t \cdot h_t^{1-\alpha}}$$

The average, continuously-compounded growth rate of aggregate output can be decomposed into the continuously-compounded growth rate of each of these components

$$\gamma_Y = \gamma_A + \alpha\gamma_{K/L} + \gamma_{Pop} + \gamma_{L/Pop} + (1-\alpha)\gamma_h, \tag{3}$$

where γ_Y is the continuously-compounded growth rate of aggregate output, γ_A is the growth rate of TFP, and so on.

All of the right-hand side terms are affected by demographic change. γ_{Pop} is (obviously) determined by demographics. Changes in labor supply on the extensive ($\gamma_{L/Pop}$) and intensive (γ_h) are partly determined by households' labor supply decisions over the life cycle and conditional on their life expectancy. Likewise, capital supply ($\gamma_{K/L}$) is partly determined by households' savings decisions over the life cycle and conditional on their life expectancy. Both changes in the age structure and selection effects will change the average productivity of each hour supplied. These demographic effects will be manifested in changes in *measured* TFP.

For illustration we compute this decomposition for the G7 group of countries for the period 1990-2007. The time period covers the decades when growth in many of the G7 countries was strong but growth in Japan was weak. This is also the period when Japan's demographics changed significantly as shown in the cohort distribution for Japan. We do not include later periods because the long-run growth effects of the aging cohort distributions are swamped by the cyclical effects of the financial crisis and ensuing recession. For the purpose of this decomposition we assume that capital's share is 1/3.

[Insert Table 1 and Table 2 about here]

Demographics are an important contributor to the growth experience of the G7 countries. One country that stands out is Japan. From the cohort distribution for Japan it is clear that Japan is undergoing an important demographic evolution. In the period from 1990 to 2007 declining labor force participation and declining hours of work account for 0.60% decline in output growth in Japan. In addition, total factor productivity (TFP) was low compared to previous decades and compared to the U.S. possible reflecting the lower productivity of older workers.

The combined effects of low fertility and increased life expectancy is shifting the cohort structure of the population. In some countries this is offset by immigration, but with more population concentrated in later cohorts this affects both labor force participation and hours worked since older people participate less and, when they do, they work fewer hours. [6]

[6] Fisher, Gorry, and vom Lehn (2016) show that changes in demographics and fiscal policy may together

3 Model economy

Growth accounting shows that a large part of both the levels of growth rates and the difference in growth rates between countries are due to changes in factor supplies. These changes and differences in factor supply may potentially be accounted for by changes in demographic structure. The remaining part – the level of and the differences in measured TFP growth – may also partially be accounted for by demographic change.

In order to determine the extent to which demographics account for changes and differences in growth, both through changes in factor supplies and through changes in TFP, a model economy must not only (and trivially) account for population growth, but also allow for factor supply decisions with respect to capital, labor on the extensive margin, and labor on the intensive margin. The evolution of demographics is persistent and predictable so a model that captures that connection between demographics and growth can be used to project the future impact of predictable demographic changes on growth. A structural model, which accounts for factor supply choices over the life cycle, could also serve as a laboratory for policy proposals to mitigate the effects of an aging population on long-run economic growth and welfare.

General equilibrium identifies two dimensions through which demographics may be important for macroeconomic phenomena: life expectancy and cohort distributions. Life expectancy is crucial for individual decision making at different ages, and the cohort distributions aggregate the decisions made by individuals of different ages. The evolution of the cohort distribution is a function of fertility rates, mortality rates (ie. life expectancy), and immigration rates. Past fertility rates only indirectly affect macroeconomic outcomes. At any point in time, the effect of past fertility rates is summarized by the current cohort distribution.

To account for labor supply over the life cycle households in the model economy must choose labor supply on the intensive margin and labor supply on the extensive margin at every date given their conditional life expectancy. Also, in order to account for labor

account for roughly half of the decline in hours worked.

supply on both margins, the model economy must account for labor-productivity over the life cycle. Individual labor productivity over the life cycle has two components: a deterministic, age-dependent, hump-shaped part and an idiosyncratic component, which is specified as a first-order autoregressive process. Finally, the disutility associated with participation in the labor market, measured in terms of lost time for leisure, varies by age.

3.1 Law of motion of the cohort distribution

The demographic structure of the population changes through changes in fertility, mortality and immigration. Demographic change can be modeled as follows: Let $x_t \in \mathbb{R}^J$ be the vector of number of members in each cohort in period t. According to time and age specific fertility rates $\varphi_{i,t}$, in each period these individuals give birth to a certain number of new individuals, and the number of newborns in period $t+1$, $x_{1,t+1}$, is the product of x_t and the vector of fertility rates φ_t. According to time and age-specific survival probabilities $s_{i,t}$ a fraction of each cohort survives to the next period. Then the law of motion of a population with survival rates as given above, but deterministic fertility, can be described by a simple $(J \times J)$ matrix[7]

$$\hat{\Gamma} = \begin{pmatrix} \varphi_1 & \varphi_2 & \varphi_3 & \cdots & \varphi_J \\ s_1 & 0 & 0 & \cdots & 0 \\ 0 & s_2 & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & \cdots & s_{J-1} & 0 \end{pmatrix},$$

where the diagonal elements $(s_1, \ldots, s_{J-1})$ are the conditional survival probabilities.

Let $m_t \in \mathbb{R}^J$ be a vector with each element representing the cohort specific number of net immigrants at time t. Denoting $\hat{\Gamma}_t$ the matrix of deterministic fertility and mortality rates at time t, the law of motion for the population may be written

$$x_{t+1} = \hat{\Gamma}_t x_t + m_t.$$

As we will see in Subsection 3.6, only life expectancy s and the cohort distribution x are directly relevant for macroeconomic outcomes. The cohort distribution completely

[7]The largest eigenvalue of the matrix Γ is the rate of growth of the population in steady state regardless of the initial condition. The eigenvector corresponding to this eigenvalue describes the share of each age group in the steady state population.

summarizes the demographic history of the economy at every date and it will be used to aggregate individual decisions.

3.2 Demographics in the model economy

The model economy is populated by up to J overlapping generations at any period of time. In order to keep the exercise as parsimonious and transparent as possible, we solve for a steady state with the cohort distribution and life expectancy at the given date. This means that the households at a given time assume that the current factor prices will prevail when they solve their dynamic decision problem.

Technically, all households are *ex-ante* identical and live up to J periods, with ages denoted by $j \in \mathscr{I} \equiv \{1, \ldots, J\}$. At every point in time, there are J different cohorts alive. Individuals remain children for J_0 periods. As children they neither consume, accumulate capital nor supply labor. After J_0 periods the households enter the economy as autonomous decision makers.

Each household faces a positive probability of death at each age. Let s_j denote the conditional survival probability from age j to age $j+1$. The unconditional probability of reaching age j is denoted s^j and is the product of conditional survival probability rates; $s^j = \prod_{i=1}^{j-1} s_i$. In the benchmark model, there are no annuity markets and a fraction of households therefore leaves unintended bequests that are redistributed in a lump-sum manner across all individuals currently alive.

In the computational experiments we will compare steady states with different demographic structure. The alternative would have been to compute a transition between two steady states (see e.g. Backus et al., 2014; Gagnon et al., 2016). By the definition of a steady state, both in the initial steady state and in the final steady state the demographic structure and factor prices must be constant. The economy would then be moved from the initial to the final steady state by imposing a path of mortality rates and cohort distributions. The households in the initial steady state will then suddenly be shocked by this transition, but they will then immediately perfectly anticipate the evolution of factor prices along the entire future convergence path.

3.3 Endowments and preferences

Households are endowed with one unit of time in each period of their lives and enter the economy with no assets, except their lump-sum share of accidental bequests. They spend their time supplying labor to a competitive market or consuming leisure.

Households are heterogeneous along three dimensions that affect their labor productivity and cost of supplying labor. First, they differ by age in their average labor productivity ψ, which governs the average productivity of an age cohort. Secondly, households of the same age face idiosyncratic risk with respect to their individual labor productivity. Let ν denote a generic realization of this idiosyncratic labor productivity uncertainty in the current period. The stochastic process for labor productivity status is identical and independent across households and follows a finite-state Markov process with stationary transition probabilities over time. Thirdly, cost of participation in the labor market is a monotonically increasing function of age.

At any given time households are characterized by (j, a, η), where j is age, a is current asset or accumulated savings, and η is their idiosyncratic labor productivity.

Households order the sequence of consumption and labor supply over the life-cycle according to a time-separable utility function

$$\max_{\{c_j,h_j\}} \mathrm{E}_{t_0}\left\{\sum_{j=j_0}^{J} \beta^{j-j_0} s_j u(c_{j,t_0+j}, h_{j,t_0+j})\right\} \tag{4}$$

where β is the subjective discount factor, s_j is the unconditional survival probability to age j, and the instantaneous utility function is defined over consumption and hours worked at age j, denoted as c_j and h_j.

The effective amount of leisure, ℓ, is given by

$$\ell = 1 - h - \theta_j \cdot i_p \tag{5}$$

where θ_j represents the disutility associated with the participation in the labor market as a function of age j and i_p is an indicator that takes a value 0 when $h = 0$ and 1 otherwise.

Following Kitao (2014) we assume that the fixed cost of participation is measured in terms of lost time for leisure and varies by age. The fixed cost of participation conditional on age j is given the following functional form

$$\theta_j = \kappa_1 + \kappa_2 j^{\kappa_3}. \tag{6}$$

Changes in labor supply are important to account for long-run growth rates. Labor supply elasticities and parametric form for preferences over labor and leisure are therefore a crucial part of the model. As the benchmark case, we use a standard additive-separable isoelastic utility function

$$u(c,h) = \frac{c^{1-\sigma}}{1-\sigma} + \chi \frac{(1-h-\theta_j \cdot i_p)^{1-\gamma}}{1-\gamma}. \tag{7}$$

The parameter χ represents the weight on utility from leisure relative to consumption, σ is the intertemporal rate of substitution, and γ is the curvature of the utility function for leisure.

3.4 Individual budgets and aggregate resource constraints

Individuals maximize expected utility subject to their period-by-period budget constraint

$$c_{j+1,t+1} + a_{j+1,t+1} = (1+r_t)a_{j,t} + w_t \cdot h_{j,t} \cdot \psi_j \cdot \eta_{j,t} + b_t, \tag{8}$$

and the constraints following from the absence of an intentional bequest motive

$$a_{J_0,t} = a_{J+1,t} = 0, \tag{9}$$

where $a_{j,t}$ represents asset holdings, r_t is the rate of return on capital, w_t is the market price of one efficiency unit of labor, and accidental bequests, ψ_j is the individual age-specific, systematic productivity component, η_j is the idiosyncratic component of an individual's productivity, and b_t, is the fraction of total inheritance or bequests received by each individual alive at time t.

The process for the exogenous uninsurable idiosyncratic productivity shocks, η_j, is specified as a first-order autoregressive process. Empirical studies indicate that a persistent autoregressive component and a transitory component accurately describes the data (see e.g. Meghir and Pistaferri, 2004; Heathcote, Storesletten, and Violante, 2010)

$$\log \eta_{j+1} = \rho \log \eta_j + \varepsilon_{j+1} \qquad \varepsilon \sim \mathcal{N}(0, \sigma^2). \tag{10}$$

3.5 Technology

We assume competitive firms demand labor and capital, supply consumption goods, and have access to a constant elasticity of substitution technology with the form

$$Y_t = K_t^{\alpha} L_t^{1-\alpha}, \tag{11}$$

where K_t and L_t represent the aggregate capital stock, and aggregate labor input (measured in efficiency units) in period t. The aggregate law of motion for capital stock is

$$K_{t+1} = (1 - \delta) K_t + I_t. \tag{12}$$

where δ is depreciation rate and I_t is aggregate net savings.

3.6 Competitive equilibrium

An equilibrium for this economy is defined by:

1. Individuals optimize and choose quantities demanded and supplied given prices

    - Each individual's optimization problem

    $$v(j, a, \eta) = \max_{h, a'} \left\{ u(c, h) + \beta \cdot s \cdot \mathrm{E}_{\eta' | \eta} v(j+1, a', \eta') \right\}$$

    - Individuals' quantity choices are aggregated by the number of individuals in each cohort

    $$K_t^s = \sum_i x_i \int_{a \times \psi} a \, \mathrm{d}\mu(a, \psi \mid i, t)$$

and

$$L_t^s = \sum_i x_i \int_{a \times \psi} h \; \psi \; \eta_i \; \mathrm{d}\mu(a, \psi \mid i, t)$$

where $\mu(a, \psi \mid i, t)$ is the stationary distribution over assets (a) and individual idiosyncratic productivity (ψ) conditional on age (i) and time (t).

2. Firms optimize and choose quantities demanded and supplied given prices

$$\max_{K_t^d, L_t^d} \left\{ Y_t - r_t K_t^d - w_t L_t^d \right\}$$

3. Markets clear: prices are set such that demand equals supply

$$\{r_t, w_t\} \; : \; K_t^s = K_t^d \;\; \text{and} \quad L_t^s = L_t^d$$

From the definition of competitive equilibrium, there are two features of demographic change that affect macroeconomic outcomes: individuals' conditional life expectancies, s, affect individual choices, and the cohort distribution, x, determines how these individual choices are aggregated.

[Insert Table 3 about here]

4 Calibration

In order to carry out the numerical simulations and compute average growth rate we first calibrate the model economy. The relevant demographic variables are the cohort distributions and the conditional survival probabilities associated with the life expectancies in the United States and Japan in 1990 and 2007. The structural preference and technology parameters of the model economy are calibrated to key moments of the United States in 1990.

[Insert Figure 4 and Figure 5 about here]

4.1 Demographics

As shown in Section 3.6 the two crucial demographic variables are individual life expectancy and cohort distribution.

Each year households face a mortality risk. The sequence of one-year annual mortality rates is computed using the algorithm described by Henriksen (2015) to match the life expectancy reported by the United Nations Population Prospects (2015) for the given country and year. The sequence of mortality rates also determines the theoretical maximum age.

Cohort distributions (Figures 4 and 5) are based on the United Nations Population Prospects (2015). We linearly interpolate to compute one-year cohort bins based on the five-year cohorts reported by the United Nations.

The cohort distributions do not necessarily match the stationary distributions associated with the mortality rates, but the competitive equilibrium may still be computed.

4.2 Preferences

Preference and technology parameters are calibrated to match moments of the United States economy in 1990. Households' preferences plays a critical role in determining individual factor supply decisions. There may be some guidance from the calibration of business cycle models. In stochastic growth models, the parametric class for preferences over consumption and leisure must be consistent with balanced growth. King, Plosser, and Rebelo (1988) showed that the preferences they put forth, often referred to as "balanced-growth preferences", were the only ones consistent with a balanced growth path. The key feature of the utility function is an income effect (of higher wages) that exactly cancels the substitution effect on hours. In the benchmark model, households have preferences that are additively separable over time, additively separable over consumption and leisure, and of the King et al. (1988) class.

Households discount the future with the product of the factor β and the country, time and age specific survival probability s. The common country-, time- and age-invariant discount factor β is set to match a capital-output ratio of 3 in the US in 1990. The parameter χ is set so that the average work hours of working individuals equal to 0.4 of disposable time as in the PSID data each year. Consistent with the King et al. (1988) class, the risk-aversion parameter σ is set at 1. γ is set equal to 4.0.

Retirement age is endogenous and individual and a function of factor prices, age-dependent fixed cost of participation, and individual productivity. The three parameters in the fixed cost of participation κ_1, κ_2 and κ_3 are calibrated to match the following three targets for the US in 1990: average participation rate of 85% at age 60 and 6% at age 70, and average retirement age at 65. The calibrated cost function is plotted in Figure 7. Households may work part time, but not less than 0.2.

Because our results will point to the labor supply elasticity as a key determinant of our findings we report the implied Frisch elasticities of labor supply which is the benchmark in the labor economics literature.

4.3 Technology

In the benchmark calibration, the CES production function has unit elasticity of substitution so we have the standard Cobb-Douglas case. The capital share parameter α is set to 0.33, a standard value in the literature. The depreciation rate is set to match a real interest rate of 5% in 1990, $\delta = 0.06$.

[Insert Figure 6 and Figure 7 about here]

4.4 Labor productivity processes

A household's labor productivity depends on two components: a deterministic age-dependent component ψ_j, and a persistent, idiosyncratic shock η.

Following Hansen (1993), we have used a hump-shaped profile for the age-specific component of individual productivity ψ_j, see Figure 6. Several contributions have later questioned this parametrization, including Casanova (2013) and Rupert and Zanella (2015). As we will show and in line with the results reported in these papers, due to selection effects average earnings are flatter than average productivity profiles.

The persistence parameter of the idiosyncratic component η of a worker's wage is set to $\rho = 0.97$ and the variance of the white noise is set to $\sigma^2 = 0.02$, which lie in the range of estimates in the literature (see, for example, Meghir and Pistaferri, 2004; Heathcote et al., 2010).

The calibrated parameters are summarized in Table 3.

5 Computational experiment

In our first exercise, we compute the model-economy equilibria associated with the demographic variables in the United States and Japan in 1990 and 2007 and compare them with results of the growth accounting exercise reported in Section 2. We do this for at least two reasons. First, Japan 1990 shared several demographic similarities with the United States at the onset of the Financial Crisis, in particular in terms of cohort distribution and life expectancy. Second, the growth experience in Japan in the 1990s shares similarities with the growth experience in the United States following the Financial Crisis. And third, this is part of the period which was referred to as the "great moderation". It may therefore provide us with a benchmark to evaluate the potential contributions of demographics to economic growth. Note that in these exercises the cohort distributions are given by the data and they reflect the baby boom and its echo as well as whatever anomalies have occurred before hand. Their evolution is driven by historical life expectancy, fertility and immigration rates . The question being addressed is how much of the observed growth experience can be accounted for by the labor supply decisions at the intensive and extensive margins where the latter decisions depend life expectancy as well as draws from the wage profile and idiosyncratic shocks.

We calibrate the structural parameters of the model economy to the United States in 1990 and solve for the steady state distributions of the economy with these structural parameters, but the demographic structure in the U.S. 1990, the U.S. 2007, Japan 1990, and Japan 2007, respectively. We then do the growth accounting on the implied data and compare it to the results of the previous exercise.

During this period there were both substantial increases in life expectancy and changes in average age and the cohort distributions. The anchor for these computations are the life expectancies and cohort distributions for Japan and the U.S. in 1990 and 2007. The cohort distributions are shown in Figures 4 and 5 and the evolution of life expectancy at birth is shown in Figure 3.

We solve for steady-state distributions instead of transitions between steady states to keep the exercise as accountable and parsimonious as possible. Computing transitions would be numerically and computationally feasible, but the economic results would necessarily hinge on choice of initial and terminal conditions and it would be difficult to assure convergence over this interval and the transitions would add little to our analysis. Moreover, the cohort distributions are anchored by the data and contain both the history and the idiosyncratic changes over the period. Since the demographics provide this anchor it makes more sense to focus on the steady state distributions.

6 Results

In order to assess the potential importance of demographic changes for economic growth over time and across nations, for reasons mentioned above we study the United States and Japan between 1990 and 2007.

[Insert Table 4 about here]

6.1 Comparing Japan and the United States 1990 to 2007

The model economy is scaled by the size of the population so demographics can trivially account for the population-growth part on average 1.10% and 0.17% annually for United States and Japan, respectively.

Since we may trivially account for the aggregate growth contribution from population growth we are interested in growth ex aggregate population growth, or, equivalently, in growth per capita. Table 4 shows the growth accounting for United States and Japan from Table 2 net of population growth.

[Insert Table 5 and Table 6 about here]

The question is to what extent the evolution of the contributions to growth observed in the growth accounting exercise reported in Section 2 are consistent with the general equilibrium economy described above.

To understand how much of the changes in growth and in total factor productivity we compute the steady states of the model for the U.S. in 1990 and in 2007 and for Japan in 1990 and 2007. We then do the growth accounting on the implied data and compare it to the results of the previous exercise.

After computing stationary distributions, factor prices and levels of aggregate variables for the two economies with their given demographic structure at the two years we did a similar growth accounting exercise on the data from the model economy. The model implied total growth over the period is given in Table 5, and the the model-implied annual growth over the period is given in Table 6.

Capital accumulation has been an important contributor to growth, both in Japan and the United States. In the model economy, changes in capital accumulation are the result of increases in longevity that affect savings decisions and changes in the cohort distribution that aggregates these decisions. Increased longevity increases propensity to save for longer life in retirement since households have to accumulate more wealth during their working years. Households accumulate wealth until they decide to retire, which for most households is in their late 60s. As the cohort distribution shifts to the right this will by itself contribute to higher capital accumulation. In addition, there is a general equilibrium effect. Lower interest rates lead households to accumulate more assets.[8]

[8]Robustness analysis with Greenwood, Hercowitz, and Huffman (1988) preferences support this. With

According to the model, the capital/output ratio in the U.S. increases from 3.0 in 1990 to 3.18 in 2007. This is a larger increase than in the data over the same period. In contrast, in Japan it raises from 3.31 to 3.64 in the model while it increased from 3.27 to 4.19 in the data. The interest rates decrease in the model by 0.5 and 0.9 percentage points, respectively. The aggregate investment-to-output ratio increases by a similar magnitude.

[Insert Figure 8 about here]

The change in capital accumulation is smaller than in most earlier models with inelastic labor supply. This is partly due to the fact that propensity to work at old ages increase with life expectancy. This highlights a crucial tension of this model, which is the calibration of the functional form and the parameters for the cost of participation as a function of age. Figure 8 shows asset profiles over the life cycle. Because there is idiosyncratic risk, the model generates dispersion in asset holdings over the life cycle. We should also point out that the time path of assets over the life cycle shows a sharper decline than is seen in actual data. Households tend not to run down their assets as they age as much as is implied by life-cycle model. This suggests that preferences incorporating bequest motives may be necessary to better capture this aspect of the data.

The model partly accounts for the contribution of declining labor supply to lower overall economic growth. For the reasons mentioned above, these results crucially depend on the calibration of the age-dependent cost-of-participation function. In the model economy, with increased life expectancy, labor market participation in the U.S. at age 60 increases from 85% in 1990 to 91% in 2007 and from 5% to 15% at age 70.

More surprising may be the contribution from demographics to measured TFP growth. This result is partly due to a composition effect and partly due to selection effects. Almost mechanically, if a larger fraction of the population is in their most productive years that will be measured as an increase in aggregate TFP. In addition there is a selection effect

these GHH preferences, which rule out income effects, capital accumulation is substantially less than with preferences that are additive in labor and leisure.

interacting with increases in life expectancy. Individuals who receive a sequence of positive idiosyncratic productivity shocks tend to supply more labor on the intensive margin and stay longer in the labor force. This effect seems to be reinforced by changes in longevity.

The results show that for the benchmark calibration about 1/6 of the level of growth for both United States and Japan, net of population growth, can be accounted for by changes in life expectancy and in the cohort distributions.

7 Robustness

Our results establish that labor-leisure and consumption-savings choices, and hence intertemporal and intratemporal elasticities, are key determinants of our findings, and more generally, key to understand the economic effects of the demographic transition.

[Insert Figure 9 and Figure 10 about here]

7.1 Frisch elasticity of labor supply

The Frisch elasticity of labor supply measures the percentage change in hours worked due to the percentage change in wages, holding constant the marginal utility of wealth (i.e., the multiplier on the budget constraint (λ)

$$e = \left.\frac{\mathrm{d}h_t/h_t}{\mathrm{d}w_t/w_t}\right|_{\lambda_t=\bar{\lambda}}$$

It is a key parameter in the design and assessment of macroeconomic models with endogenous labor supply. Macroeconomic models typically report Frisch elasticities somewhere in the range of 2 to 4. In contrast, the seminal microeconometric estimates of the Frisch elasticity which are determined from hours and wage fluctuations on an individual basis are in the range of 0 to 0.5.

In order to estimate the Frisch elasticity of our model economy we carry out the experiment as an "M.I.T. shock", i.e., as an unexpected, never-again-to-occur departure from a steady state. Given the solution to the value function

$$v(j,a,\eta)=\max_{h,a'}\left\{u(c,h)+\beta\cdot s\cdot \mathrm{E}_{\eta'|\eta}v(j+1,a',\eta')\right\},$$

wages are suddenly increased without any change in the value function and the continuation values, i.e. holding constant the marginal utility of wealth.

We solve for

$$\left\{h,a'\right\}=\arg\max_{h,a'}\left\{u(c,h\mid w=\bar{w})+\beta\cdot s\cdot \mathrm{E}_{\eta'|\eta}v(j+1,a',\eta')\right\}$$

and

$$\left\{h,a'\right\}=\arg\max_{h,a'}\left\{u\left(c,h\mid w=\bar{w}\cdot(1+\varepsilon)\right)+\beta\cdot s\cdot \mathrm{E}_{\eta'|\eta}v(j+1,a',\eta')\right\}$$

aggregate these individual labor supply decisions by the stationary distribution over age, asset holdings and individual productivity. Since there is no future wealth/welfare effect we then have an estimate of the Frisch elasticity of labor supply.

The estimated Frisch elasticity in the benchmark calibration is 0.095, which is in the range of microeconomic estimates.[9] This is consistent with the more detailed environment here in which we are picking up labor supply decisions at a very detailed level by 5 year age cohorts and then aggregating them. Figure 10 plots the Frisch elasticity as a function of age. It is very small for younger workers because, although they might respond to factor price changes, they are already working. It is only among older workers where the response to these shocks is sizeable. There are no aggregate productivity shocks but only idiosyncratic individual productivity shocks calibrated to match the features of the data. But, in this experiment, the "M.I.T. shocks" act like productivity shocks.

[Insert Table 7 about here]

[9] See Rogerson and Wallenius (2009) and Chetty, Guren, Manoli, and Weber (2011).

7.2 Cost of participation

As we have documented, a substantial part of the declining GDP growth rates are due to lower labor market participation rates at the intensive and extensive margins. We also know that individual labor supply declines gradually with age. The two crucial features of the model economy to endogenize labor supply decisions both on the intensive and extensive margins are the age-dependent cost-of-participation function and idiosyncratic shocks to labor productivity.

There are important issues regarding the measurement of the idiosyncratic shocks to labor productivity, but they are, in principle, directly measurable. The cost-of-participation function, however, is not directly inferable. In our benchmark calibration we calibrate the three parameters by targeting average number of working years, labor market participation rate at 60, and labor market participation at 70. It turns out the results are highly sensitive to the calibration of these parameters.

In the benchmark calibration, $\{\kappa_1, \kappa_2, \kappa_3\}$ are calibrated to $\{0.0531, 0.00149, 1.4178\}$. If instead calibrating the model to participation rates at 60 and 65, the calibrated values are $\{0.0531, 0.000298, 2.780\}$, ie. a substantially more convex function. The results using this calibration gives the results in Table 7. As we see, with this alternative calibration, a larger fraction of the growth history may be accounted for. This is primarily because as the cost-of-participation function increases faster with age, the old-age propensity to participate in the labor market changes less with increases in life expectancy.

This discussion abstracts from important developments in labor force participation such as the trends in female labor force participation and decreasing prime-age male labor supply. These are important issues, which could be addressed within the current framework when appropriately extended.

7.3 GHH preferences

Our results establish that the labor supply elasticity and the trade-off between labor supply and leisure are key determinants of our findings, and more generally, key to understand the economic effects of the demographic transition.

One issue that arises in this framework is that increases in life expectancy induce increases in savings of households to provide for future consumption. This is turn causes the interest rate to fall and the capital stock to increase. This is an important phenomenon as the high capital/output ratios and decreasing real interest rates in Japan can attest. But a higher capital stock means higher wage rates which affect labor supply.

There are different classes of preferences that shut down some of these effects. Substituting the preferences in the benchmark model calibration with Greenwood et al. (1988) preferences – that shut down the wealth effect on the labor supply;

$$u(c,h) = \frac{1}{1-\sigma}\left(c + \chi \frac{(1-h-\theta_j \cdot i_p)^{1-\gamma}}{1-\gamma}\right)^{1-\sigma}.$$

These preferences dampen the increase in capital accumulation as life expectancy increases.

7.4 Productivity and earnings profiles

There has been debate about how productivity on average varies with age. E.g. Rupert and Zanella (2015) argue that the wage profile does not decline with age, while the earnings profile does. Our results are broadly consistent with this finding. Due to selection effects, despite the deterministic profile for ψ_i, there is little decline in the average productivity of, and hence wage for, a unit of time worked.

7.5 Bequests and life-cycle asset profiles

In the benchmark economy, all savings are for life-cycle reasons. In other words, all bequests are unintentional or so-called "accidental". The realized bequests in the model are the assets accumulated by households for life-cycle purposes and left by those who passed away in the previous period. They are distributed lump sum to the households alive in this period. As a consequence, the households in the model deaccumulate assets faster than observed in data and that the life-cycle asset profile is too steep.

Parents care about their offspring. The exact form of altruism within a family matters for whether our life-cycle model provides a good approximation for life-cycle consumption-savings decisions. Parents care about certain dimensions of the consumption vector of their offspring instead of their total utility. This is sometimes referred to as "impure altruism."

To study whether introduction of bequests would quantitatively affect our results we study a particular type of "impure altruism" where households derive utility from their bequest, so called "warm glow preferences". The households Bellman equation then takes the form

$$v(j,a,\eta) = \max_{h,a'} \left\{ u(c,h) + \beta \left[s \cdot \mathrm{E}_{\eta'|\eta} v(j+1,a',\eta') + (1-s) \cdot \tilde{u}(a') \right] \right\},$$

where $\tilde{u}(a') = (a')^{1-\sigma}/(1-\sigma)$.

With these preferences, we have to recalibrate the model. In order to match the initial capital-output ratio of 3 for the United States in 1990, the time preference parameter is recalibrated to 0.949. The asset profile with the recalibrated preference parameter is given in Figure 9. As we see the asset profile is somewhat flatter than in the model without bequests and warm-glow preferences. However, after the model is recalibrated the quantitative results hardly change at all.

[Insert Table 8 about here]

8 Projections for future growth

The model economy we described in the previous section can also be used to project the expected impact of demographic changes on the growth experience of countries going forward. Using the projections for life expectancies and cohort distributions reported by the United Nations *World Population Prospects*, we can compute the projected impact on future growth.

Using exactly the same calibration as in our baseline model we project the impact on growth from 2015 to 2030. Over this period the predicted life expectancy in Japan grows from 84.09 to 86.21 years. The predicted life expectancy for the U.S. grows from 79.57 years to 81.79 years.

The impact of these changes for average annual growth rates are shown in Table 8.

These results are quite striking. They suggest that over time demographic changes are a drag on economic growth in the United States and more so for the U.S. than for Japan which has been ahead in the demographic transition.

9 Concluding remarks

The slowdown in growth in the world's most advanced economies may be due in part to the combination of increased life expectancy and a shift to the right in the cohort distributions. Growth accounting exercises show that lower growth is because of decrease in labor supply, both on the intensive and the extensive margin, and lower TFP growth. Increased capital accumulation has somewhat mitigated the decrease in growth coming from these other factors. With our calibrated model, we found that a parsimonious overlapping generations model in which households make labor supply and savings decisions based on (changing) conditional life expectancy can partly account for the growth rate experience of Japan and the United States between the start of Japan's "lost decades" and the start of the financial crisis.

The objective of the paper is to provide a transparent framework to analyze historical data, and, potentially, make predictions for future growth rates. This framework identifies some the key factors to account for the effect of demographic change on economic growth. In particular, it shows that elasticities of labor supply, of intertemporal substitution, and of substitution between capital and labor are crucial for both these results and for modeling the effects of the demographic transition on future economic growth. Further refinement of the calibration may show that these demographic factors may account for an even larger part of economic growth.

This framework may also serve as a laboratory to address future challenges such as fiscal sustainability if an increase in the number of retirees coincides with lower economic growth. As we have shown, the incentive effects from capital and labor may not only affect labor supply on the intensive and extensive margin, but also aggregate productivity growth. Within this parsimonious framework it is possible to analyze the effects of policy responses both on aggregate growth and on welfare.

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A Tables

Table 1: Growth accounting G7

	γ_Y	γ_A	$\alpha \cdot \gamma_{K/L}$	γ_{Pop}	$\gamma_{L/Pop}$	$(1-\alpha) \cdot \gamma_h$
United States	2.76	1.28	0.52	1.10	-0.10	-0.05
Canada	2.61	0.45	0.80	0.99	0.52	-0.15
UK	2.48	1.53	0.72	0.40	0.09	-0.25
France	1.78	0.97	0.45	0.54	0.19	-0.36
Germany	1.67	1.03	0.55	0.18	0.28	-0.38
Italy	1.30	0.30	0.54	0.32	0.26	-0.13
Japan	1.11	0.75	0.83	0.17	-0.16	-0.47

Table 2: Growth accounting United States and Japan

	γ_Y	γ_A	$\alpha \cdot \gamma_{K/L}$	γ_{Pop}	$\gamma_{L/Pop}$	$(1-\alpha) \cdot \gamma_h$
United States	2.76	1.28	0.52	1.10	-0.10	-0.05
Japan	1.11	0.75	0.83	0.17	-0.16	-0.47
Difference	1.65	0.53	-0.31	0.93	0.06	0.42

Table 3: Calibration

Demographics		
x	Cohort sizes	UN
s	Conditional survival probabilities	UN, Henriksen (2015)
Preferences		
β	Subjective discount factor	0.968
χ	Weight on leisure	0.4123
σ	Consumption utility curvature	1.0
γ	Leisure utility curvature	4.0
$\kappa_1, \kappa_2, \kappa_3$	Cost of labor force particaptation	0.0531, 0.00149, 1.4178
Labor productivity process		
ρ	Persistence parameter	0.97
σ^2	vVriance	0.02
ψ	Age-dependent productivity	PSID
Technology and production		
α	Capital share of output	1/3
δ	Depreciation rate of capital	0.06

Table 4: Data: Growth accounting net of population growth

	$\gamma_{Y/Pop}$	γ_A	$\alpha \cdot \gamma_{K/L}$	$\gamma_{L/Pop}$	$(1-\alpha) \cdot \gamma_h$
United States	1.66	1.28	0.52	-0.10	-0.05
Japan	0.94	0.75	0.83	-0.16	-0.47
Difference	0.72	0.53	-0.31	0.06	0.42

Table 5: Model: Total growth accounting net of population growth 1990-2007

	$\gamma_{Y/Pop}$	γ_A	$\alpha \cdot \gamma_{K/L}$	$\gamma_{L/Pop}$	$(1-\alpha) \cdot \gamma_h$
United States	4.34	1.86	2.61	3.28	-3.41
Japan	1.62	0.54	4.33	-1.03	-2.22

Table 6: Model: Annual growth accounting net of population growth 1990-2007

	$\gamma_{Y/Pop}$	γ_A	$\alpha \cdot \gamma_{K/L}$	$\gamma_{L/Pop}$	$(1-\alpha) \cdot \gamma_h$
United States	0.26	0.11	0.15	0.19	-0.20
Japan	0.10	0.03	0.25	-0.06	-0.13

Table 7: Model: Growth accounting net of population growth 1990-2007

	$\gamma_{Y/Pop}$	γ_A	$\alpha \cdot \gamma_{K/L}$	$\gamma_{L/Pop}$	$(1-\alpha) \cdot \gamma_h$
United States	0.35	0.22	0.35	-0.07	-0.14
Japan	0.24	0.14	0.56	-0.14	-0.33

Table 8: Growth projections -

	$\gamma_{Y/Pop}$	γ_A	$\alpha \cdot \gamma_{K/L}$	$\gamma_{L/Pop}$	$(1-\alpha) \cdot \gamma_h$
Japan	-0.27	0.01	0.17	-0.45	0.01
United States	-0.33	0.02	0.15	-0.38	-0.12

B Figures

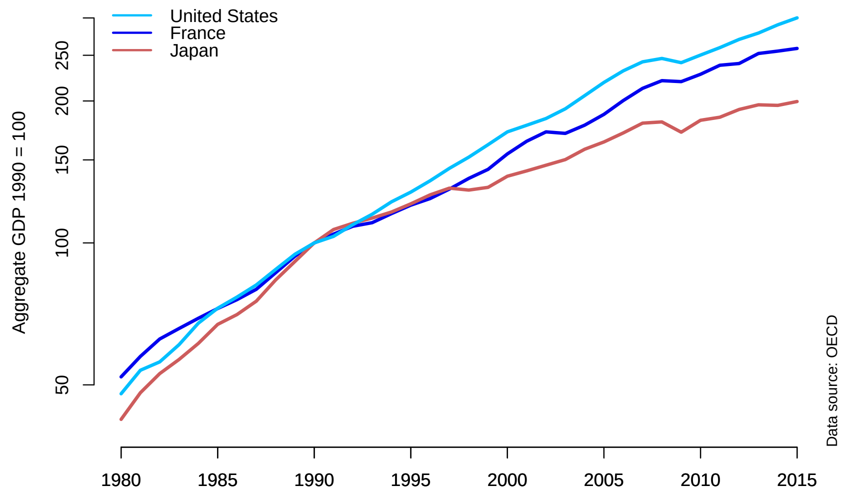

Figure 1: Aggregate Real GDP United States, Japan and France

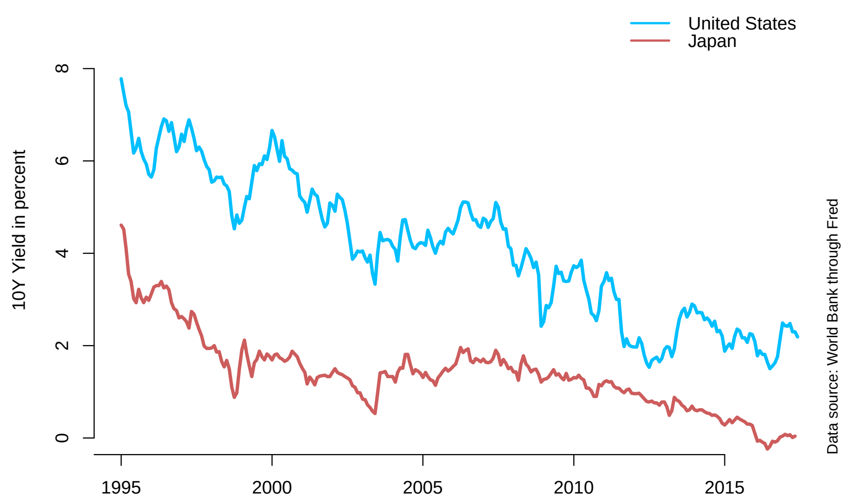

Figure 2: Yield 10Y Government Bonds United States and Japan

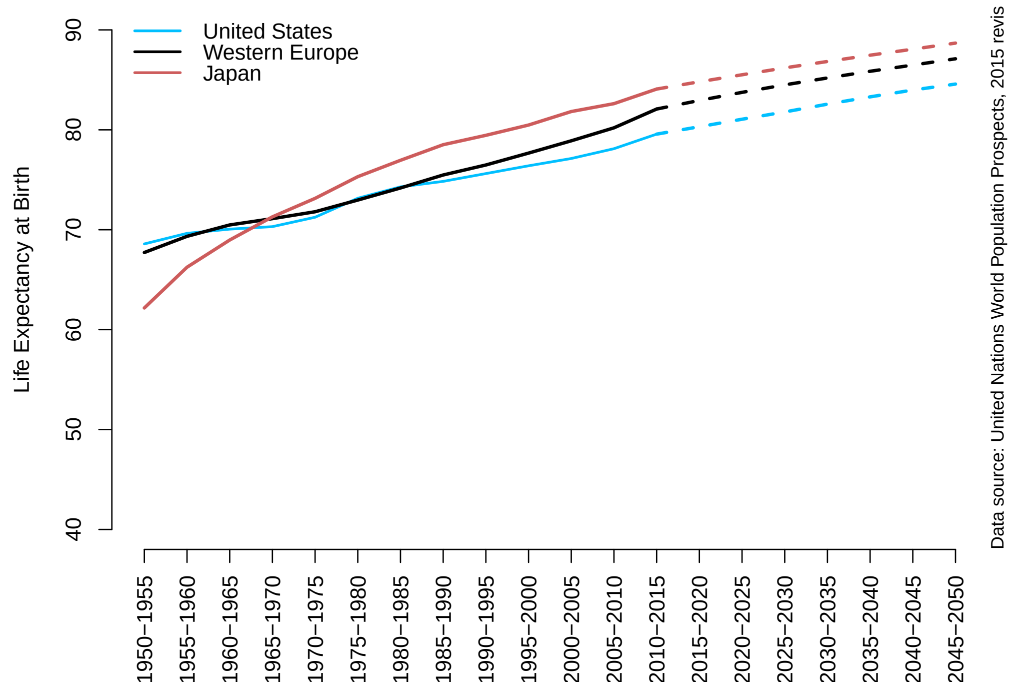

Figure 3: Life expectancy at birth, United States, Japan, and Western Europe

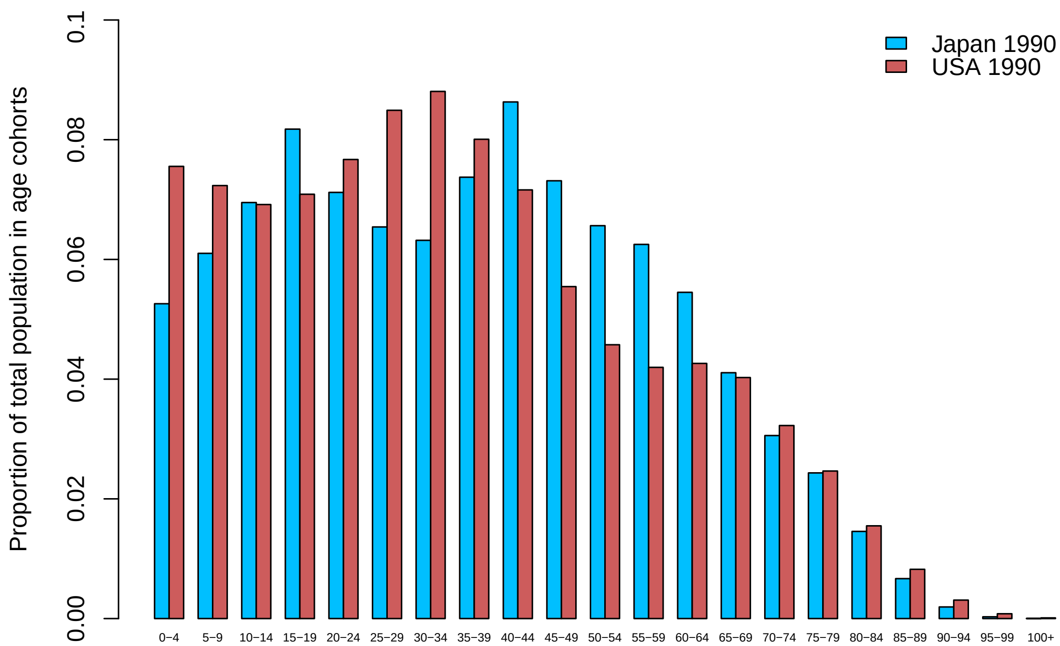

Figure 4: Cohort distribution United States and Japan 1990

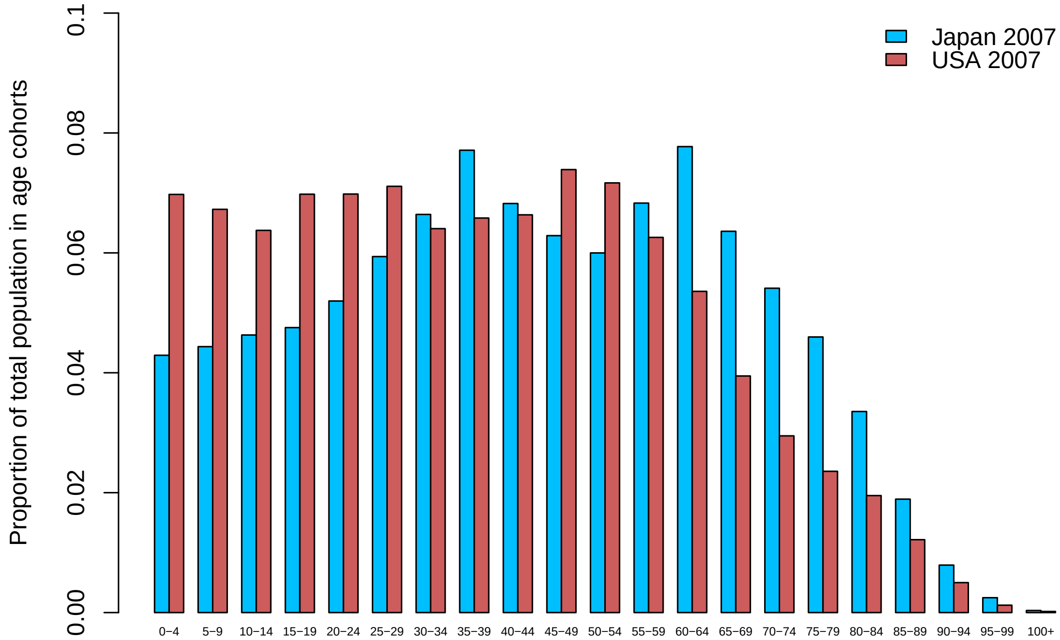

Figure 5: Cohort distribution United States and Japan 2007

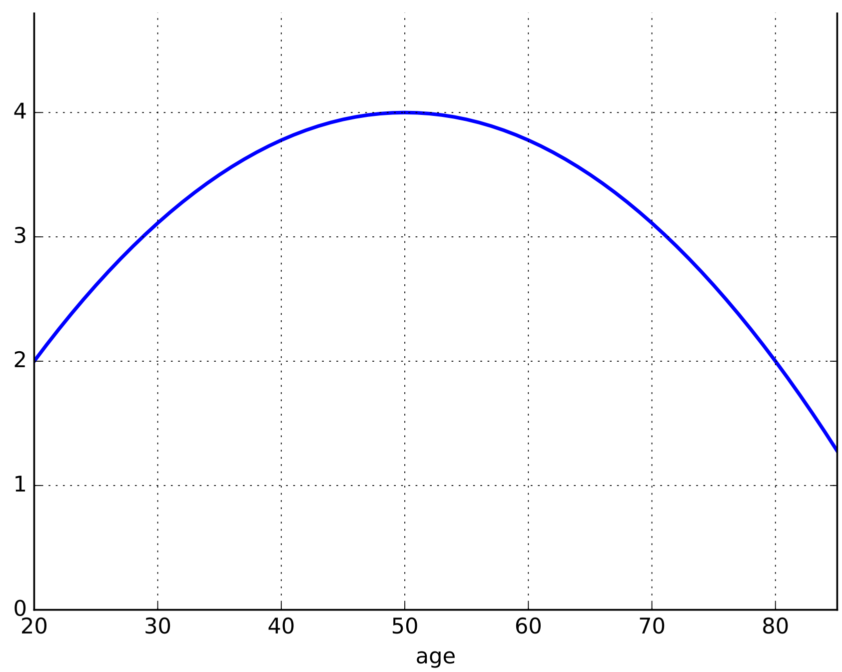

Figure 6: Life-cycle productivity profile

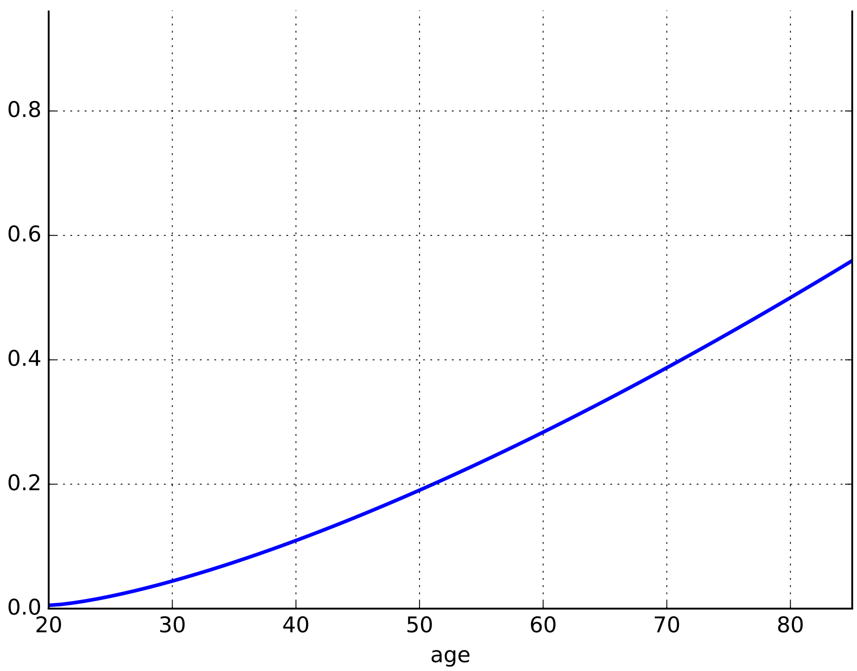

Figure 7: Participation cost at different ages

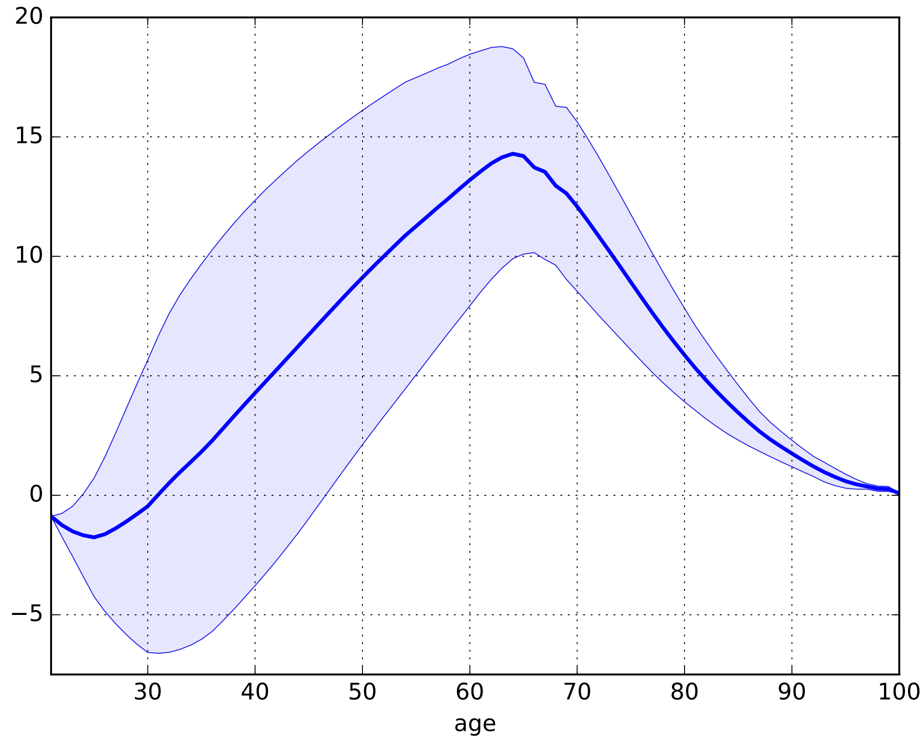

Figure 8: Model asset profile over the life cycle given US life expectancy and equilibrium factor prices in 1990. The shaded area is on standard deviation in each direction.

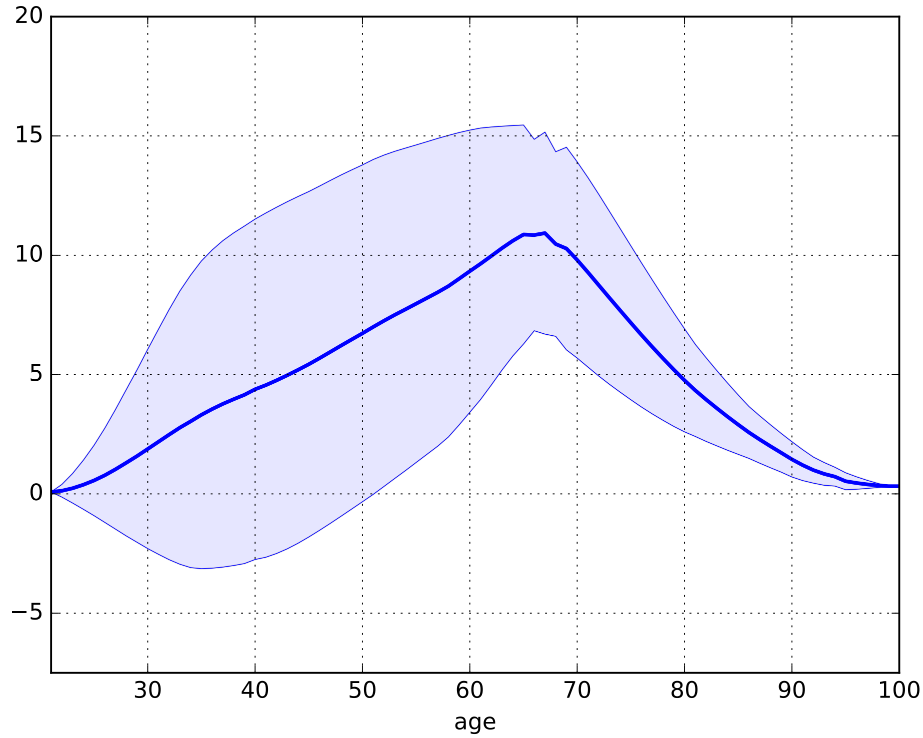

Figure 9: Model asset profile over the life cycle given US life expectancy and equilibrium factor prices in 1990 with warm-glow bequest preference. The shaded area is one standard deviation in each direction.

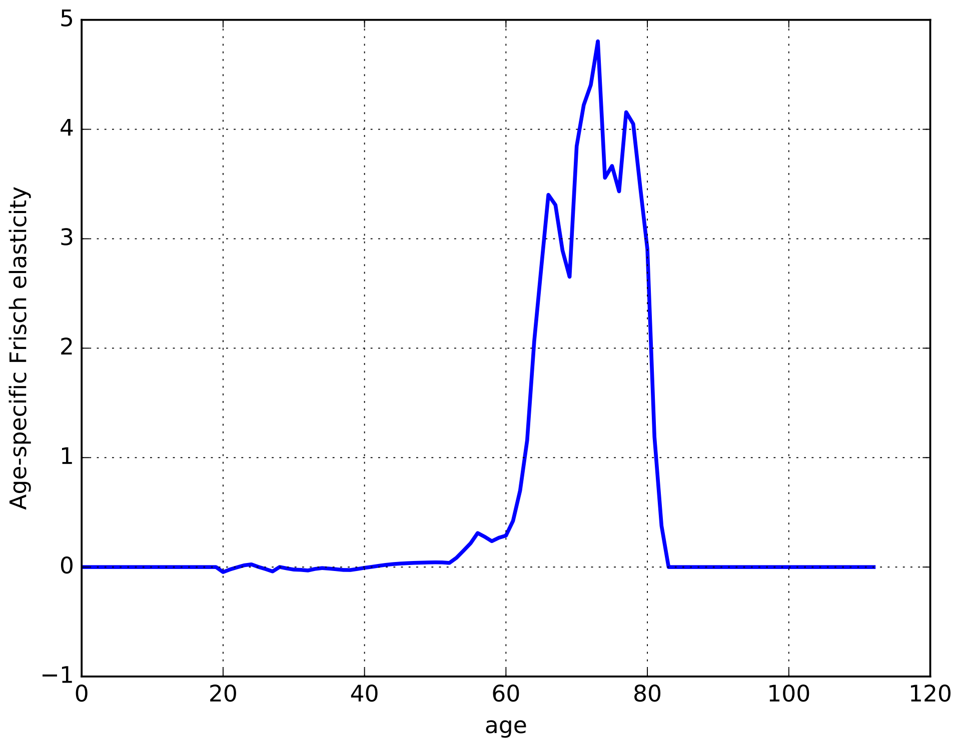

Figure 10: Estimated Frisch elasticity by age