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Population Aging and Its Macroeconomic Implications: A Framework for Analysis

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Abstract

This paper develops a model to examine the macroeconomic implications of population aging. Using a general equilibrium framework, the analysis examines the various channels through which changes in demographics affect the economy. Age-earnings profiles are taken to summarize differences in effective labor supply across age groups and to help determine changes in consumption and saving behavior that occur over an agent's lifetime. Aggregating these supply- and demand-side effects, the implications of aging on economic activity and fiscal policy are then examined.

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I. INTRODUCTION

Population aging will be a defining feature of the economic landscape in the new century. According to demographic projections, the share of elderly dependents in OECD countries will rise to unprecedented levels, reaching nearly one senior for every two workers by the middle of the twenty-first century. These demographic changes will undoubtedly have profound social and economic implications. In terms of its macroeconomics impact, population aging could have important ramifications for saving, investment and growth.

Using a life-cycle perspective, this paper develops a general equilibrium framework to examine the economic and policy implications of population aging. The economic effects of demographic changes are manifested through two main channels: (1) on the demand side, population aging has implications for aggregate consumption and saving propensities and (2) on the supply side, changes in the age structure have implications for labor supply. Using this analytical framework, the economic implications of demographic shocks are simulated in industrial countries, and the implications for public finances are examined against the backdrop of aging populations.

To quantify the impact of aging in a dynamic macroeconomic framework, a key component to the analysis is the age-earnings profile. Over the life cycle, individuals can expect a *hump-shaped* pattern to labor earnings. Initially, as agents join the workforce, they can expect a rising path of earnings, reflecting productivity gains that come from work experience and seniority wages that reward work service. Eventually, labor earnings level off and decline as agents move into retirement. This life-cycle earnings path is important in quantifying both supply- and demand-side implications of demographic change. On the supply side, age-earnings profiles characterize changes in relative productivity and labor supply that occur over an individual's working life. On the demand side, changes in the expected path of labor income affect the consumption and saving plans of consumers. Using age-earnings profiles to summarize differences in effective labor supply across age groups and to help determine changes in consumption and saving behavior, the macroeconomic and policy implications of aging populations are then examined.

Compared to previous studies, the present analysis suggests a more complex relationship between saving behavior and population aging. Previous work has largely been based on the macroeconomic time series evidence and simple reduced-form coefficients from (linear) saving regressions on dependency ratios; these studies tend to find very large negative effects on saving rates from increasing elderly dependency rates.[2] This paper takes a more structural approach, where consumption and saving behavior builds on the modern life-cycle paradigm. Within this multi-cohort framework, younger agents tend to be net borrowers, reflecting the fact that permanent income exceeds current income; mature agents tend to be large net savers at the peak

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[2]See for example Meredith (1995) for a summary of the macroeconomic evidence on demographics and saving with an analytical application to Japan.

of their earnings potential; finally, the elderly also tend to save (albeit to a lesser degree).[3] In this setting, agents' saving behavior is more closely tied to the microeconomic evidence on household saving, including elderly agents who do not generally dissave.[4] Consequently, population aging does *not* guarantee a large, uniform decline in saving, particularly when other factors such as increasing longevity are also taken into account. In fact, saving rates can rise or fall depending on the stage of the demographic adjustment process.[5] Moreover, the results suggest that a wide range of economic outcomes are possible from population aging, depending on the nature of the underlying demographic shock.

The paper is organized as follows. Section II describes the analytical framework that includes population dynamics and age-earnings profiles; Section III describes demographic changes in major industrial countries using structural time-series estimates of their birth rates; Section IV presents simulations of the model based on demographic shocks for the United States and Japan; Section V concludes.

II. Life-Cycle Model

The model extends the Blanchard-Yaari-Weil overlapping agents framework to include demographic dynamics. In particular, demographic change is introduced into the model through cohort-specific birth rates and time-varying population growth. Second, age-dependent features are introduced through age-earnings profiles to give the model an important life-cycle dimension. It should be noted that demographic dynamics stemming from changing birth rates are taken as parametric but thus avoids relying on any particular model of fertility.

[3]Saving by the elderly reflect precautionary motives in the face of lifetime uncertainty and retirement. Agents tend to guard against the possibility of outliving their labor income through attaining a target level of financial wealth (and asset income). See Abel (1985), Davies (1981), and Faruqee and Laxton (2000).

[4]See Weil (1989) for a discussion of the tension between the saving implications of demographics from the macroeconomic and microeconomic evidence. See Lusardi (…) for evidence on household saving rates.

[5]Cutler, et al (1990) examine population aging using the Ramsey growth model, augmented for a changing support ratio—i.e., the share of effective workers to consumers. They find that saving (and investment) rates generally decline with population aging, but that short-run saving and saving net of investment tend to *rise* in the country aging more rapidly.

A. Population Growth

The analytical framework begins with the overlapping agents model of Blanchard (1985), extended to the case of population growth dynamics.[6] The basic law of motion for the population is given by:

$$\frac{\dot{N}(t)}{N(t)} = n(t) = b(t) - p(t), \tag{1}$$

where N is the population level and n is the growth rate—equal to the difference between the "birth" rate b and the death rate p;[7] dot variables through out denote derivatives with respect to time. Integrating-up equation (1) over time, yields an expression (up to a constant of integration) for the size of the total population at any moment in time:

$$N(t) = e^{\int_{-\infty}^{t} n(v)dv} = e^{\int_{-\infty}^{t} [b(v) - p(v)]dv}. \tag{2}$$

Equation (2) shows that population size evolves according to the accumulation of past changes to its growth rate—i.e., the past difference between birth and death rates, which determines the size of the current population as growth factor times the size of the initial population.[8, 9]

B. Dependency Ratio

To examine various demographic issues, it is useful to define measures that characterize the age distribution of the population. Note that the size of the population, which until now has

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[6]See Buiter (1988) for a description of the model under constant population growth.

[7]The birth rate b is defined as the arrival rate of new adults and N is the adult population. With constant birth and death rates, the number of agents belonging to a generation s at time s (i.e., at the time they are born), as a proportion of the contemporaneous population, is given by $n(s,s) = bN(s)$; the number survivors from that cohort at time $t \geq s$ is then given by $n(s,t) = bN(s)e^{-p(t-s)}$, where p is the common death rate facing all agents.

[8]In deriving equation (2), the following boundary condition is required: $\lim_{t \to -\infty} \ln N(t) = 0$, or equivalently, $\lim_{t \to -\infty} N(t) = 1$. Based on this initial condition (normalization), the constant of integration drops out and can be ignored.

[9] Without loss of generality, the growth factor can be renormalized so that the population at time t can be expressed in terms of the population at time zero, normalized to unity:

$$N(t) = e^{\int_{0}^{t} [b(v) - p(v)]dv}; \; N(0) = 1.$$

been defined in *relative* terms—vis-à-vis a reference population, can also be defined in *aggregative* terms—as the sum of existing individuals across all generations (indexed by s):

$$N(t) = \int_{-\infty}^{t} n(s,t)ds = \int_{-\infty}^{t} b(s)N(s)e^{-p(t-s)}ds \ . \tag{3}$$

In writing this expression, note that we have assumed a fixed death rate to simplify the discussion. [10]

Similarly, we can define the *elderly dependency ratio* as that proportion of the total population above a certain age as follows:

$$\phi(t) = \int_{-\infty}^{j(t)} \frac{n(s,t)}{N(t)} ds \ ; \ 0 < \phi < 1, \tag{4}$$

where ϕ measures the relative cohort size, as a share of the total population, of individuals older than some threshold age level—indexed by $j(t)$. Assuming that this age definition does not change, the index $j(t)$ moves with time to include new dependents, who have just reached the threshold age at each moment in time (i.e., $j'(t) = 1$). In the case where birth rates are constant, it can be shown that the dependency ratio ϕ would also be constant.[11] Otherwise, the dependency ratio evolves over time according to the time derivative of equation (4) above:

$$\dot{\phi}(t) = \frac{n(j(t),t)}{N(t)} - [p + n(t)]\phi(t). \tag{5}$$

At each moment in time, the change in the dependency ratio is determined by the relative size of new dependents attaining the threshold age, less the proportion of the elderly $p\phi$ who die each period and accounting for growth in the population base $n\phi$—i.e., the scaling variable

C. Age-earnings Profiles

To incorporate a life-cycle dimension to the analysis, we consider age-earnings profiles where labor income initially rises with age and experience, before eventually declining with retirement. To introduce lifetime income profiles, we assume that individual labor input (which is inelastically supplied) varies in effective terms across agents from different generations. Specifically, we assume the *effective* labor supply (measured in efficiency units) has the following time series pattern:

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[10]Because the probability of death is *independent* of age (i.e., to allow for aggregation), changes in p have minimal distributional implications, but have important aggregative implications for population growth.

[11]With steady population growth, the dependency ratio would settle down to its long-run value: $\overline{\phi} = e^{-\bar{b}\Delta}$, where $\Delta \equiv t - j(t)$ and $\bar{b}$ are constants.

$$l(s,t) = \left[a_1 e^{-\alpha_1(t-s)} + a_2 e^{-\alpha_2(t-s)}\right]\mu(t)\,;\, t \geq s\,, a_1 > 0 > a_2, \alpha_2 > \alpha_1 > 0. \tag{6}$$

In this expression, the first exponential term can be interpreted as the decline in an individual's labor supply over time, reflecting (gradual) retirement. This impact on effective labor supply is partially offset, however, by the second exponential term which represents the productivity gains associated with age and experience. [12] Together, these two factors imply that the behavior of effective labor supply is non-monotonic or hump-shaped—initially rising, but eventually declining over a person's lifetime.[13] The last term μ in equation (6), which is not age-specific, represents general labor productivity growth that depends on economy-wide considerations (e.g., technology).[14]

Assuming equation (6) summarizes the age-specific features underlying differences in labor earnings across cohorts, we can express individual labor income as the product of the aggregate wage rate and individual labor supply:

$$y(s,t) = w(t)\, l(s,t). \tag{7}$$

Thus, for a given wage rate, the relationship between age and earnings will exhibit a similar (hump-shaped) time profile as between age and labor supply; this profile has been documented empirically by age-earnings distributions in a broad cross-section of countries.[15]

Aggregating over all individuals, it follows that total labor income is:

$$\begin{aligned} Y(t) &= \int_{-\infty}^{t} w(t) l(s,t) n(s,t) ds \\ &= w(t) L(t), \end{aligned} \tag{8}$$

[12]For convenience, we further assume that $a_1 + a_2 = 1$; so effective labor supply of the cohort born at time t=0 is normalized to unity at birth. To insure that effective labor supply is always increasing initially (i.e., at t=s), we also require: $a_1 > \alpha_2/(\alpha_2 - \alpha_1)$.

[13] It is assumed that demographic changes do *not* impact on relative labor supply and, hence, the shape of the relative earnings profile. Relative changes in (say) elderly participation rates over time could violate this assumption. Historically, however, the age-earnings profile has been fairly stable over time; estimates for the U.S. and Japan can be found in Faruqee and Laxton (2000), and Muhleisen and Faruqee and (2001), respectively.

[14]Henceforth, we assume constant productivity growth: $\mu(t) = e^{\mu t}$, where the aggregate productivity index at time zero is normalized to unity.

[15]See for example Jappelli and Pagano (1989). Reorganizing terms implicit in (7), one could also express labor income as a function of a cohort-specific wage $w(s,t)$—commensurate with individual productivity.

where L is aggregate labor input, also measured in efficiency units.[16]

Using the definition of individual labor supply in (6), one can also write L as the sum of two components $L_1 + L_2$—representing aggregates of the factors underlying the age-earnings function in (7).[17] In the presence of demographic dynamics, the law of motion governing the behavior of aggregate labor input can then be written as:

$$\begin{aligned} \dot{L}(t) &= \dot{L}_1(t) + \dot{L}_2(t), \\ &= b(t)N(t)e^{\mu t} + (\mu - p - \alpha_1)L_1(t) + (\mu - p - \alpha_2)L_2(t). \end{aligned} \tag{9}$$

Intuitively, equation (9) defines changes in L as depending on the effective labor supply of new entrants to the workforce and the death and productivity changes among existing workers.

D. Consumption

Agents are assumed to maximize expected utility over their lifetimes subject to a dynamic budget constraint. Specifically, the evolution of financial assets $a(s,t)$ for an individual or household is determined by its saving, equal to the difference between income and consumption:

$$\dot{a}(s,t) = (r+p)a(s,t) + y(s,t) - \tau(s,t) - c(s,t) \tag{10}$$

where r is the interest rate, $y - \tau$ is disposable labor income, and c is consumption, all expressed in real terms (units of consumption).[18] Ignoring any capital market imperfections, consumption is be based on an agent's permanent income. Explicitly, optimal consumption (with log utility) is given by:[19]

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[16]In Blanchard (1985) and Faruqee, Laxton and Symansky (1997), age-earnings profiles were introduced by distributing aggregate income to individuals according to age-specific weights. The problem with this "top-down" approach is that changes in the age distribution have *no* aggregative implications by construction. Here, we proceed in the opposite fashion—building from "bottom-up" to obtain total labor income and allowing distributional changes in the demographic age structure to have aggregate implications.

[17]Specifically, we define: $L_k(t) = \int_{-\infty}^{t} l_k(s,t)n(s,t)ds$, where $l_k(s,t) = a_k e^{-\alpha_k(t-s)}e^{\mu t}$ for k=1,2 and, thus, $\dot{L}_k(t) = a_k b(t)N(t)e^{\mu t} - (\alpha_k + p)L_k(t)$.

[18]The term $pw(s,t)$ in the dynamic budget constraint reflects the efficient operation of the life insurance or annuities market. See Yaari (1965) or Blanchard (1985).

[19]For the simulations later, we assume constant relative risk aversion (CRRA) utility; see Blanchard (1985). See Faruqee and Laxton (1999) for a discussion of the implications of CRRA utility and varying the intertemporal elasticity of substitution.

$$c(s,t) = (\theta + p)\left[a(s,t) + h(s,t)\right]. \tag{11}$$

where θ is the rate of time preference and $h(s,t)$ is a measure of an agent's *human wealth*—equal to the present value of future labor income.[20] Because labor income and human wealth eventually decline over a person's lifetime with retirement, the saving behavior implied by equation (11) suggests that agents eventually build up financial wealth $a(s, t)$ to ensure a certain level of retirement consumption.[21]

Consequently, unlike traditional life-cycle models—e.g., Diamond (1965)—the elderly do *not* dissave or run down financial assets here due to life-time uncertainty. Instead, agents attain a certain target level of financial wealth as a precaution against the possibility of outliving their labor income.[22] The build-up in asset income allows agents to maintain consumption levels well into retirement. This behavioral feature allows the multi-cohort framework to avoid a common criticism of standard life-cycle models that posit large negative saving rates among retirees.[23]

Aggregating again, total consumption as a function of (financial and human) wealth can be expressed as follows:

$$C(t) = (\theta + p)\left[A(t) + H(t)\right]. \tag{12}$$

where A is aggregate financial wealth and H is aggregate human wealth. Financial wealth consists of domestic equity and bond holdings and, in the open-economy case, holdings of net foreign assets; $A \equiv K+B+F$. As for aggregate human wealth—reflecting the present value of economy-wide labor income streams, its behavior can be characterized as follows:

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[20]For a fixed real interest rate, individual human wealth can be written as:

$$h(s,t) \equiv \int_t^\infty [y(s,v) - \tau(s,v)]\, e^{-(r+p)(v-t)}\, dv.$$

Correspondingly, the dynamic equation for an individual's human wealth is given by:

$$\dot{h}(s,t) = (r + p)h(s,t) - [y(s,t) - \tau(s,t)].$$

[21] See Faruqee and Laxton (2000).

[22] See Davies (1981) and Abel (1985) for similar models with precautionary saving and accidental bequests. Technically, the presence of annuities markets in this model ensures that financial wealth at the time of death is exactly zero—i.e., there are no bequests. Leaving this end-point issue aside, however, the more relevant point is that to guard against longevity risk, agents choose *not* to decumulate financial assets below some target level up until the end of life.

[23]Numerous studies at the household level find scant evidence of dissaving among the elderly. For a recent, see Browning and Lusardi (1996) and the references cited therein.

$$\dot{H}(t) = \frac{d}{dt}\int_{-\infty}^{t} h(s,t)N(s,t)ds$$
$$= h(t,t)b(t)N(t) + r(t)H(t) - [Y(t) - T(t)], \tag{13}$$

where T is total labor taxes and $Y - T$ is total disposable labor income. Equation (13) shows that the incremental change in the stock of aggregate human wealth is influenced by the additional human wealth of the *newest* generation.

Given the shape of the labor income profile, the evolution of human wealth for the newest generation at each moment in time can be summarized as follows:

$$\dot{h}(t,t) = \dot{h}_1(t,t) + \dot{h}_2(t,t)\,; \tag{14}$$
$$\dot{h}_1(t,t) = (r + p + \alpha_1)h_1(t,t) - a_1(1-\tau)w(t)e^{\mu t}\,; \tag{15}$$
$$\dot{h}_2(t,t) = (r + p + \alpha_2)h_2(t,t) - (1-a_1)(1-\tau)w(t)e^{\mu t}\,. \tag{16}$$

The human wealth components $h_1$and h_2 derive from the factors underpinning the time profile of effective labor supply and, thus, labor earnings over an individual's lifetime.[24]

Equations (9) and (13) summarize the role that demographic dynamics play on economic behavior through both supply-side and demand-side channels. On the supply side, changes in the demographic profile of the economy impact the affective supply of labor, given the differences across age groups summarized in the age-earnings profile. On the demand side, aggregate consumption and saving behavior will also be affected through aggregate human wealth dynamics in the face of life-cycle income and demographic change.

E. Pension System

To complete the model, we lastly turn to government policy. A pension system can be introduced into the framework as follows. Consider first the simple case of a lump-sum transfer scheme:

$$tr(s,t) = \begin{cases} -\alpha(t); s > j(t) \\ +\beta(t); s \le j(t) \end{cases} \tag{17}$$

---

[24]Given age-earnings profile and assuming proportional labor income taxes —i.e., $\tau(s,t) = \tau y(s,t)$, human wealth can be written as: $h(s,t) = h_1(s,t) + h_2(s,t)$, where $h_k(s,t) = \int_t^{\infty}(1-\tau)\omega(v)l_k(s,v)\,e^{-(r+p)(v-t)}dv$ for k=1,2.

where the transfers $tr(s,t)$ paid or received by individuals, depending on their age. Younger generations ($s > j(t)$) pay into the system while older agents or pensioners ($s \leq j(t)$) receive a benefit. Redefining the scheme in terms of payroll tax financing is straightforward. In that case, individual contributions would be proportional to wage income: $\alpha(s,t) = \tau_{ss} y(s,t)$.

For any transfer scheme, a full-financing condition can be written as follows:

$$\int_{-\infty}^{t} tr(s,t)N(s,t)ds = 0. \tag{18}$$

This general condition must hold for the transfer scheme to be deemed fully financed (i.e., no unfunded liabilities from the transfer system). Full-financing in the specific case of lump-sum transfer is then given by:

$$\frac{\beta(t)}{\alpha(t)} = \frac{1-\phi(t)}{\phi(t)}. \tag{19}$$

Equation (16) shows the well-know condition that the benefit-to-contribution ratio must equal the support ratio—i.e., the number of working-age relative to elderly dependents. If full-financing is not satisfied, there would exist a financing gap (positive or negative) reflecting the degree of over- or underfunding. In the case of a shortfall, the deficit in social security would have to be closed through general tax revenues or government borrowing.

The dynamics of aggregate human wealth in the presence of social security would be modified as follows:

$$\dot{H}(t) = h(t,t)b(t)N(t) + r(t)H(t) - [Y(t) - T(t)] - \int_{-\infty}^{t} tr(s,t)N(s,t)ds, \tag{20}$$

The dynamic equation now includes the current financing gap from the pension system. If social security benefits are fully financed by contributions, the direct effects of the pension system on total human wealth would net out to zero. Otherwise, aggregate human wealth would be directly affected by the amount of over- or underfunding of benefits.[25]

The dynamics of human wealth for new entrants would be also be modified. Under a payroll tax-financed pension scheme, the laws of motion are as follows:

$$h(t,t) = h_1(t,t) + h_2(t,t) + h_\beta(t,t); \tag{21}$$

$$\dot{h}_1(t,t) = (r + p + \alpha_1)h_1(t,t) - a_1(1 - \tau - \tau_{ss})w(t)e^{\mu t}; \tag{22}$$

$$\dot{h}_2(t,t) = (r + p + \alpha_2)h_2(t,t) - (1 - a_2)(1 - \tau - \tau_{ss})w(t)e^{\mu t}; \tag{23}$$

[25]Notice that even in the case of a fully-financed system, the evolution of individual human wealth (in footnote above) is affected by the presence of social security to the extent that current contributions are not exactly offset by the present value of future pension benefits.

$$\dot{h}_\beta(t,t) = (r + p)h_\beta(t,t) - \beta(t + \Delta)e^{-(r+p)\Delta} \tag{24}$$

With social security, individual human wealth includes terms associated with net transfers. The components $h_1$and h_2 now include social security contributions τ_{ss} as part of labor income taxes, but agents also (eventually) receive benefits. The present value of the benefit stream is represented by h_β, and Δ reflects the number of years before the newest generation of workers will be eligible to receive social security benefits (i.e., reach retirement age).

III. Demographic Dynamics

To examine the implications of demographic changes, we now turn to the time series data. Demographic dynamics represent a changing age structure of the population and generally stem from underlying changes in fertility and mortality. While other types of events such as wars or immigration can affect the demographic profile in relatively short period, a changing age structure (e.g., rising dependency ratio) usually reflects the consequences of gradual changes or trends in birth rates and life expectancy. These demographic shocks fall into one of two basic types—permanent or transitory.

A well-known example of a permanent demographic shock is the *demographic transition*, where fertility rates durably fall as economies advance to higher stages of economic development. The fall in fertility is often preceded or accompanied by a fall in mortality rates. Clear examples of sustained declines in fertility rates are Japan and Italy [see appendix]. A well-known example of a transitory demographic shock is the *baby boom* in the post-war United States, when birth rates remained persistently high relative to their historical average, leading to a boom generation who significantly outnumbered the members of preceding and subsequent cohorts. See figure 1.

A. Structural Time-series Model

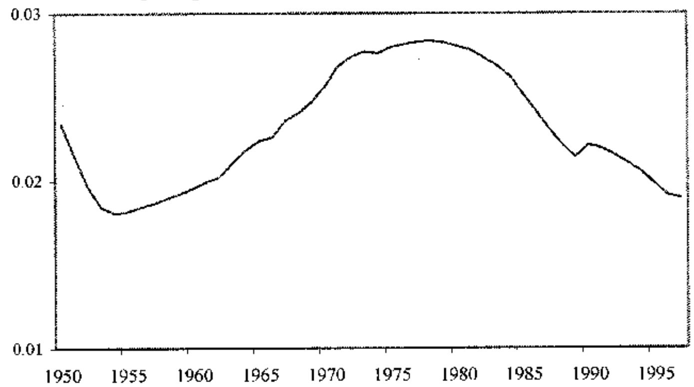
To characterize demographic movements, we examine the time-series behavior of the birth rate. Persistent dynamics in the birth rate resulting from both transitory and permanent shocks can be represented using hyperbolic functions; see appendix. Specifically, we summarize the historical path of the birth rate for major industrial countries as the outcome of a series of "step" and "bump" processes. The time-series model also provide estimates of the long-run birth rate needed to generate demographic projections later. Alternative specifications for each time series are tested pairwise (i.e., wald test) in selecting the structural models that are reported.

In the case of the United States, for example, the historical hump-shape pattern for the U.S. birth rate for the period 1950 to 1997 can represented in terms of (the derivative of) the hyperbolic tangent function. Specifically, the following structural time-series model summarizes the U.S. data well:

$$\hat{b}(t) = 0.02 + 0.01\left[\frac{d}{dt}\tanh\left(\frac{t - 1977.2}{10.5}\right)\right]; \tag{15}$$

$$\bar{R}^2 = 0.92\,;\ S.E.E. = 0.001\,;\ D.W. = 0.33;$$

Figure 1. United States "Birth" Rate, 1950-1997
(youngest cohort as a share of adult population)



Data Source: U.S. Bureau of Labor

The estimates suggests that the long-run birth rate for the United States is 2 percent; but in 1977, at the height of the baby boom, the birth rate reached a transitory peak that was 1 percentage point higher.[26]

B. Other Industrial Countries

The birth rate processes for the other major industrial countries over the period 1950-2015 can be represented by similar structural time series models.[27]

Canada:

$$\hat{b}(t) = \frac{0.024+0.018}{2} - \frac{0.024-0.018}{2}\left[\tanh\left(\frac{t - 1989.4}{4.6}\right)\right] + 0.01\left[\frac{d}{dt}\tanh\left(\frac{t - 1975.9}{9.0}\right)\right];$$

$$\bar{R}^2 = 0.97\,;\ S.E.E. = 0.001\,;\ D.W. = 0.16$$

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[26]Based on the corrected standard errors (not shown), the non-linear least squares estimates of all the parameters are significant at the 1 percent level.

[27]All of the estimated parameters in the subsequent times series equations were found to be significant at the 1 percent level.

Canada, for example, experienced a simultaneous baby boom with the United States—seen by a transitory rise in the birth rate that peaked around 1976, described by the last term in the above expression. But according to the first and second terms in the equation, Canada also had a permanent or "step" decline in its long-run birth rate from 0.024 to 0.018 over the sample period with a transition mid-point in 1989.[28]

France:

$$\hat{b}(t) = \frac{0.021 + 0.016}{2} - \frac{0.021 - 0.016}{2}\left[\tanh\left(\frac{t - 1956.2}{2.6}\right)\right] + 0.01\left[\frac{d}{dt}\tanh\left(\frac{t - 1978.0}{16.2}\right)\right];$$

$$\overline{R}^2 = 0.90\ ;\ S.E.E. = 0.001\ ;\ D.W. = 0.19$$

Similar to Canada, France's birth rate is characterized by a baby boom as well as a transition to lower fertility. The transitory boom of 1 percent in the birth rate peaked in 1978, in addition to an overall "step" decline in the long-run birth rate from 0.021 to 0.016.

Italy:

$$\hat{b}(t) = \frac{0.027 + 0.013}{2} - \frac{0.027 - 0.022}{2}\left[\tanh\left(\frac{t - 1958.3}{5.1}\right)\right] - \frac{0.022 - 0.013}{2}\left[\tanh\left(\frac{t - 2000.0}{5.2}\right)\right];$$

$$\overline{R}^2 = 0.98\ ;\ S.E.E. = 0.001\ ;\ D.W. = 0.17$$

In the case of Italy, the estimates suggests a halving of the long-run birth rate—from 0.027 to 0.013 over the sample period. This long-run fall occurs in two "step" declines: first, the long-run birth rate has fallen from 0.027 to 0.022—with the transition mid-point between these rates in 1958; a second fall from 0.022 to 0.013 is ongoing with the transition mid-point projected for the current year 2000.

Japan:

$$\hat{b}(t) = \frac{0.035 + 0.014}{2} - \frac{0.035 - 0.031}{2}\left[\tanh\left(\frac{t - 1956.5}{1.9}\right)\right] - \frac{0.035 - 0.031}{2}\left[\tanh\left(\frac{t - 1974.6}{3.2}\right)\right]$$
$$- \frac{0.020 - 0.014}{2}\left[\tanh\left(\frac{t - 2001.2}{3.9}\right)\right];$$

$$\overline{R}^2 = 0.99\ ;\ S.E.E. = 0.001\ ;\ D.W. = 0.39$$

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[28] Based on the Wald test, the Canadian data favor a time series model that allows *both* a permanent "step" decline and a transitory "bump" increase in the birth rate over a model that allows *only* the latter. The same cannot be said for the United States over the historical sample period (see figure 1), although there is some evidence of a small "step" decline if projected years (to 2015) are also included.

For Japan, the time pattern of the birth rate is qualitatively similar to Italy's. The birth rate exhibits a significant permanent decline over the sample—occurring in three downward steps from 0.035 to 0.031, then from 0.031 to 0.02, and finally from 0.02 to 0.014, with the transition mid-points occurring in 1956, 1975, and 2001, respectively.[29]

United Kingdom:

$$\hat{b}(t) = \frac{0.019+0.017}{2} - \frac{0.019-0.017}{2}\left[\tanh\left(\frac{t - 1994.8}{3.6}\right)\right] + 0.004\left[\frac{d}{dt}\tanh\left(\frac{t - 1970.1}{3.9}\right)\right] + 0.004\left[\frac{d}{dt}\tanh\left(\frac{t - 1985.4}{5.8}\right)\right];$$

$$\bar{R}^2 = 0.96\ ;\ S.E.E. = 0.0004\ ;\ D.W. = 0.23$$

For the United Kingdom, the time series model best approximating the historical data shows a slight "step" decline from 0.019 to 0.017 plus two transitory "bump" increases in the birth rate, each about ½ percentage points in 1970 and in 1985.[30]

Plots of the historical (and projected) birth rates and the fitted values from the structural time series estimates are shown for the other G-7 countries in appendix figures A2-A6. Although the time patterns are distinct in each case, there is a general decline in the overall birth rate, signifying a decline in the inflow rate of young adults into the economy.

C. Demographic Projections

Using structural time-series representations for the birth rate and assumptions for future population growth, one can construct long-run projections for the demographic structure of these economies.[31] In particular, using the dynamic equation for the dependency ratio in (5) and the long-run implications for the birth rate associated the estimated time-series equations, we

[29]In the case of Japan, the Wald test favors three step declines over two declines; see figure A7.

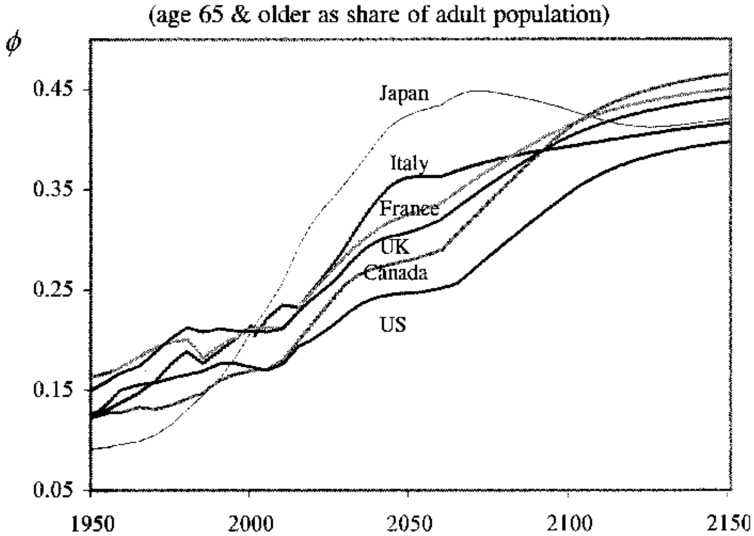
[30]The Wald test favors a step decline, albeit a small one, over no permanent (step) change in the birth rate in the case of the U.K.

[31]Note that the death rate p is determined implicitly by the difference between b and n. Because the model assumes a common death rate independent of age, the model tends to *overpredict* the share of elderly in the population; see appendix. To compensate, a uniform adjustment factor of +0.5% was added to the birth rate series; this increase in the inflow rate of new adults tends to "correct" the distributional implications of the common death rate assumption. To match a given population growth rate, p also reflects this uniform adjustment.

project dependency rates assuming zero population growth—i.e., a stationary population—in steady state.[32] The evolution of dependency ratios is shown in Figure 2.

As can be seen from the figure, the dependency ratio is expected to rise substantially in every country, particularly Japan. The rise in the dependency ratio is the smallest in United States. On average, the share of elderly in the adult population is projected to more than double from around 15 percent to around 40 percent by the end of the century.

Figure 2 -Elderly Dependency Ratio, 1950-2200
(age 65 & older as share of adult population)



IV. Demographic Simulations

The macroeconomic implications of population aging are examined for the cases of Japan and the United States. To simplify matters, the impact of each country's population dynamics is examined in isolation with the (world) interest rate taken as given. This small open

[32]The projections assume stationary populations by 2150. To achieve zero population growth, the fertility rate is assumed to decline (from its predicted levels) 1-for-1 with population growth where applicable, thereby preserving existing mortality rates. In the case of Japan and Italy where growth is initially negative, this approach projects a *recovery* in birth rates. In the case of the U.S. and Canada, immigration tends to produce higher population growth for a given birth rate (i.e., lower residual mortality rate); so in these cases, most but not all of the decline in population growth is attributed to a fall in fertility.

economy assumption, however, can be straightforwardly relaxed.[33] The reference or baseline scenario is one where the population is stationary at the country's prevailing birth rate in 2000.[34]

The effects of aging are first examined in the absence of social security; the second set of simulations examine the effects of demographic change in the presence of social security transfers.

A. Economic Impact of Aging

In the case of Japan, the fertility rate is projected to fall dramatically from its current level, leading to a falling rate of population growth that turns negative at some point. Consequently, Japan's demographic dynamics suggest a rapidly aging and declining population over the next hundred years. The birth rate is assumed to eventually recover somewhat to ensure a stationary final population; this lead to some overshooting in the dependency ratio. The top two panels in Figure 3 show these aspects of demographic change in Japan relative to the baseline scenario with a stationary population. Relative to the reference scenario, the demographic shock consists of a decline in the death rate-i.e., an increase in longevity—and an even larger decline in the birth rate—i.e., a shrinking population—for a long period of time. As for the age distribution, the share of elderly is expected to rise substantially as the shock unfolds.

The effects of demographic change in Japan are shown in the lower panels of Figure 3. Initially, the adult population expands for several years but then quickly begins to contract. Output too contracts with an aging and declining population, and income per capita is lower in the long run as the decline in effective labor exceeds the decline in the population. Investment also declines as capital shedding occurs with a shrinking labor force.[35] Saving rates, however, generally increase early on in the aging process as the rate of inflow of young adults—who tend to be net borrowers—decline. Also, the fall in the mortality rate suggests an increase in

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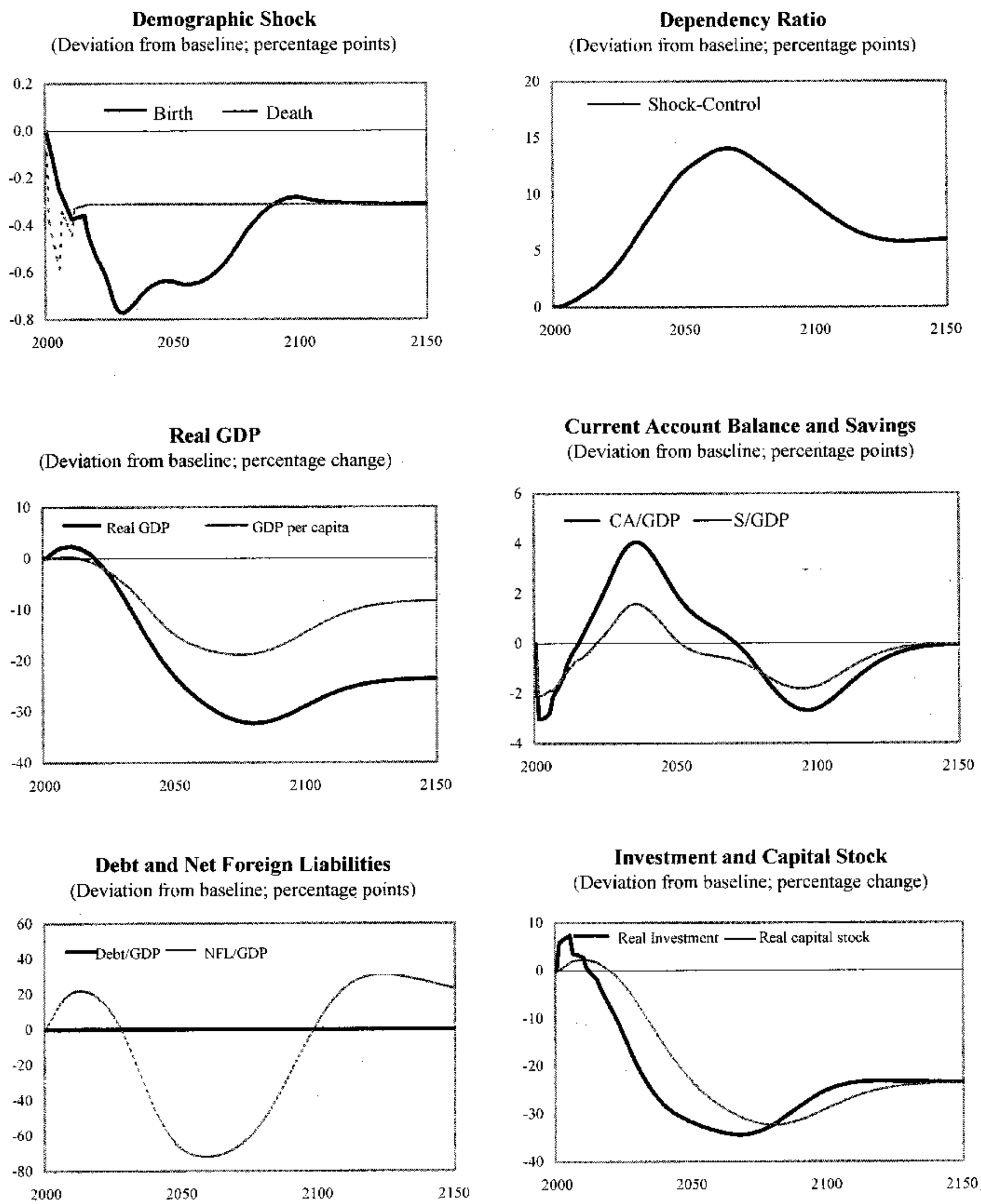
[33]In a multi-country setting, aging globally would have implications for the world real interest rate. These effects are ignored here, but could be easily modeled with the closed-economy version of the model.

[34]Consumption is assumed to be interest inelastic—i.e., the intertemporal elasticity of substitution is small (0.4); the rate of time preference is taken to be 4 percent. Investment is based on neoclassical q-theory; a fixed equity risk premium is also added to yield a sensible capital-output ratio (2 ½); see Faruqee and Laxton (2000). The production function has the traditional Cobb-Douglass specification with labor share is taken to be 0.6, and (exogenous) TFP growth is 1 percent per annum.

[35]A look at factor prices finds that wages increase with a falling birth rate as labor becomes more scarce, until the process of capital shedding is complete. This is consistent with findings that suggest that smaller cohorts benefit from higher labor income relative to larger cohorts

Figure 3. Japan --Demographic Shock



longevity and planning horizons which act to boost saving.[36] Later on, saving rates decline as the aging process matures and the birth rate recovers. Current account dynamics include oscillations between surplus and deficit. After an initial deficit, the current account balance generally improves as saving rates increases and investment rates fall. Eventually, as saving rates decline, the current account turns into deficit as an older population consumes the net foreign assets it had accumulated when Japan was younger.

The case of the United States (Figure 4) is qualitatively different. Here, a more gradual decline in fertility follows a baby boom when birth rates were temporarily high. The result is a more gradual aging of a population that continues to expand. Output and investment levels continue to grow with the population. By construction, large fall in mortality rates (relative to baseline) tends to boost saving and the current account at the outset. Thereafter, the current account ratio tends to decline over time with an expanding economy and the increase in investment accompanying a growing labor force. Eventually, as the population begins to age, the current account position improves, as the inflow of young adults wanes. In the very long run, the current account balance and saving rates decline again as the share of elderly reaches its pinnacle.

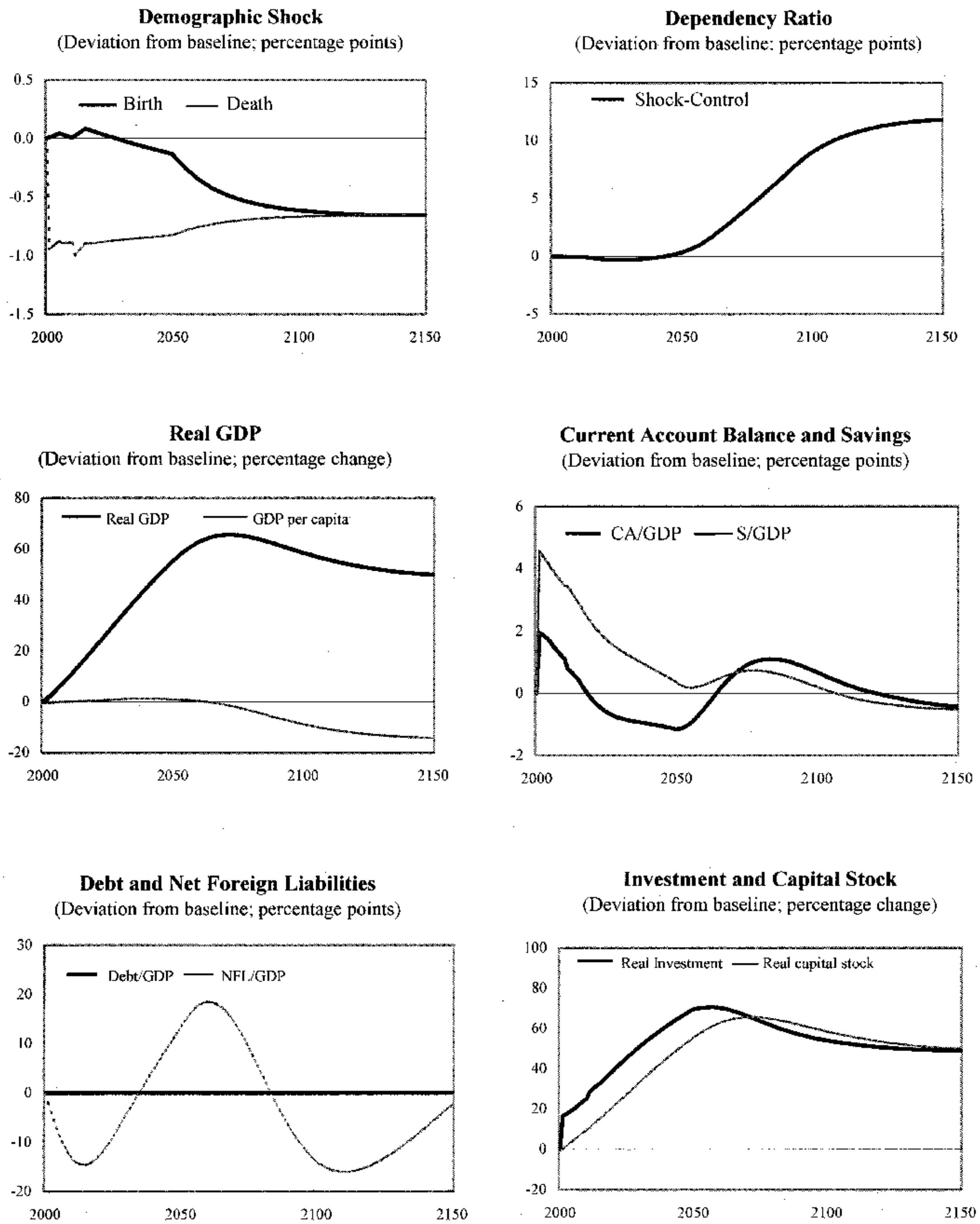
In both economies, per capita income levels (relative to baseline) *decline* with aging, as the share of elderly—who provide less labor in effective terms—rises. This demographic change suggests that as labor supply falls relative to the population, output per person would also fall for a given rate of long-run productivity growth.

B. Population Aging and Social Security

To illustrate the impact of aging on fiscal policy and the economy, the simulations of the same demographic shock are repeated in the presence of social security. As before, the baseline assumes a stationary population. In the stationary baseline, a pension transfer scheme now exists where contributions are set at 10 percent of wage income and contributions match benefits—i.e., the system is fully financed. In the face of demographic change, contribution and benefit *rates* are assumed to remain constant at their baseline values with the financing gap being covered through the issuance of government debt. Note that this experiment is only intended to be illustrative. This simple setup does not capture particular aspects of social security in either country; for example, in the United States, the social security system currently has a substantial trust fund as contributions have exceeded benefits for some time.

[36] The effects of a decline in the "birth" rate—i.e., the arrival rate of new adults—on saving depends on the extent to which these younger agents can borrow. The presence of liquidity constraints would alter this impact; see Muhleisen and Faruqee (2001) for an application of the model to Japan that includes liquidity constraints.

Figure 4. U.S. Demographic Shock



The motivation here is to examine more generally the effects of demographics in the case where the fiscal balance is directly affected.[37]

The effects of aging in Japan in the presence of a social security system are shown in Figure 5. With fixed benefit rates, social security expenditures rise as a share of GDP as the share of seniors in the population expands. Without an increase in contribution rates, government debt needs to increase to cover the shortfall in net transfers. Other taxes need to rise eventually to meet higher interest obligations on the debt. The extent to which public debt rises depends on the extent and timing of the tax increase. The demographic impact on output and investment (not shown) is the same as before, given a fixed world interest rate and fixed technology. However, the presence of social security tends to push national saving and the current account lower as fiscal deficits emerge. In the absence of pension reform, rising social expenditures lead to a substantial build up in public and external debt. The case of the United States (not shown) would exhibit similar implications from social security.[38]

V. Concluding Remarks

This paper takes a structural approach using the modern life-cycle paradigm to examine the macroeconomic implications of population aging. Within this multi-cohort framework, the economic effects of demographic change are manifested through two main channels: demand-side effects through changing consumption and saving propensities and supply-side effects from changes in (effective) labor supply. To quantify these effects, the analysis relies on the information in age-earnings profiles to assess the changes in relative productivity and labor supply and the changes in the consumption and saving behavior that result from a changing age structure of the population.

The analysis suggests a more complex relationship between saving behavior and population aging than in many previous studies. Population aging does *not* guarantee a large, uniform decline in saving. In fact, saving rates can rise or fall depending on the stage of the aging process. Moreover, the country experiences from aging can vary significantly depending on the nature of the underlying demographic shock. These country differences are highlighted by comparing the economic effects of aging in Japan and the United States.

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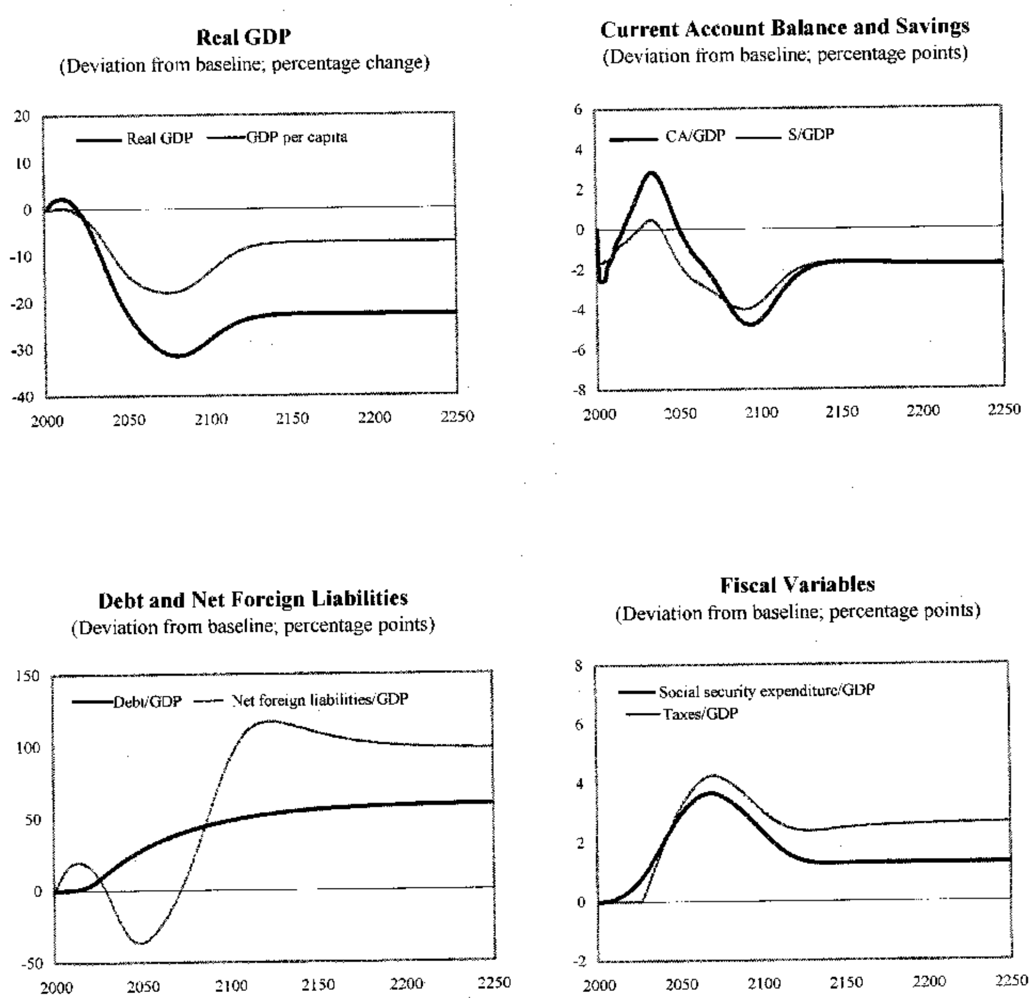
[37]Muhleisen and Faruqee (2001) consider an extended model that includes specific features of the social security system in Japan. The effects of pension reforms are also examined, including the role of other forms of tax revenue (i.e., VAT) to finance benefits.

[38]In a multi-country setting, the external balance implications of population aging would depend on relative demographic dynamics across countries. In this context, the U.S. is aging relatively slowly and, thus, might not see larger current account deficits given that other industrial countries are aging more rapidly. In the case of Japan, the build up in external debt may be more modest given that other countries are also aging to various degrees.

Figure 5. Japan--Demographic Shock with Social Security



In Japan, a dramatic collapse in the post-war fertility rate underlies a rapidly aging *and* declining population. The contraction in the population, in turn, suggests a decline (relative to a stationary baseline) in output and investment as the workforce contracts. Saving rates and the current account generally *increase* at the early stages of the demographic shift with the increase in longevity and the sharp fall in the share of young adults. Eventually, at later stages of the aging process, saving rates decline and the current account turns into deficit as an older population consumes the net foreign assets it had accumulated when Japan was younger.

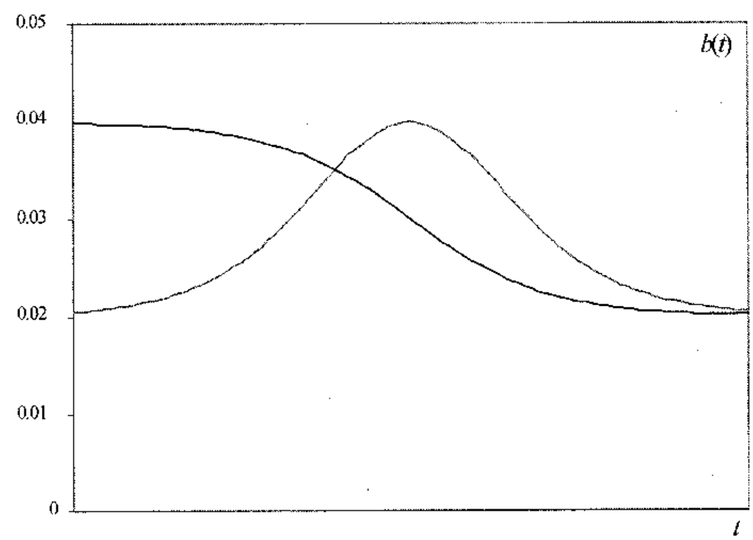
In the United States, the direct impact of aging is somewhat different. Here, a more gradual decline in fertility implies more gradual aging of the population that continues to expand. Output and investment levels also grow with the population. Early on in the adjustment, the current account tends to decline due to the increase in investment accompanying a growing labor force. As the population begins to age more rapidly, the current account balance and private saving rates increase, as the inflow of young adults diminishes. A transcendent feature of population aging is a decline in per capita incomes, reflecting the decline in labor (in efficiency units) relative to the total population as the share of elderly rises.

In the presence of social security, population aging exerts pressure on the fiscal position through higher transfers paid to a growing group of seniors. In the absence of reform to benefit or contribution rates, social security expenditures would rise relative to receipts and tend to push the fiscal balance toward deficit. The fall in public saving with an aging population leads to a decline in national saving and the current account relative to the case where social security is absent. The framework could also be extended to examine a wide range of issues regarding social security reform, e.g., changes in benefit and contribution rates or retirement age. The theoretical framework would allow analysis of such policy issues in a context where the endogenous response of private agents and the macroeconomic implications of population aging are also incorporated.

Hyperbolic Functions

In the model, demographic dynamics evolve according to the time series behavior of the birth rate. To the extent that the dynamics are relatively smooth over time, we can use standard hyperbolic functions to characterize these long-run processes.[39] The figure A1 below presents examples of both permanent and transitory dynamics in the birth rate $b(t)$.

Figrue A1. Permanent versus Transitory Changes in Fertility



In the case of a permanent decline in fertility—e.g., the demographic transition, the time series model can be expressed in terms of the hyperbolic tangent function:

[39]As a quick primer on hyperbolic functions, note that the hyperbolic sine, cosine, and tangent functions are given by:

$$\sinh(x) = \frac{1}{2}(e^{x} - e^{-x}), \cosh(x) = \frac{1}{2}(e^{x} + e^{-x}), \tanh(x) = \frac{\sinh(x)}{\cosh(x)}.$$

These functions possess certain properties that are broadly similar to their counterpart trigonometric functions such as:

$$\cosh^2(x) - \sinh^2(x) = 1, \int \cosh(x)dx = \sinh(x), \int \sinh(x)dx = \cosh(x).$$

$$b(t) = c_0 - c_1\left[\tanh(t-k)\right];\ c_0 = \frac{\bar{b}_0 + \bar{b}_1}{2},\ c_1 = \frac{\bar{b}_0 - \bar{b}_1}{2}. \qquad \text{(A1)}$$

In equation (A1), $\bar{b}_0$ and $\bar{b}_1$ represent the initial and final steady-state birth rates, and k is a phase-shift parameter, marking the point in time when the birth rate is exactly mid-way through the transition process from one long-run rate to another (i.e., $b(k) = c_0$).

Similarly, transitory dynamics in the birth rate—e.g., baby boom, can be expressed in terms of the derivative of the hyperbolic tangent function:

$$b(t) = c_0 + c_1\left[\frac{d}{dt}\tanh(t-k)\right];\ c_0 = \bar{b}, c_1 = b_1 - \bar{b}. \qquad \text{(A2)}$$

In equation (A2), the phase-shift parameter k denotes the point in time where the temporary rise in the birth rate reaches its apex at the level b_1 .

These two hyperbolic specifications are sufficiently flexible to approximate a very broad range of the time paths. Used in various combinations, they can approximate a particular evolution as the realization of permanent and transitory shocks; see for example figures A2-A6. And while other functional forms can also produce similar "step" and "bump" processes like those in equations (A1) and (A2), the hyperbolic specifications have the further advantage of straightforward integral and derivative properties, allowing for greater analytical tractability.

Empirical estimates of the path for the birth rate using the hyperbolic specification are shown for the major industrial countries in figures A2-A6. Dashed lines indicate fitted values from the estimated hyperbolic equations.

Figure A2 - Canada "Birth" Rate, 1950-2015
(youngest cohort as percent of adult population)

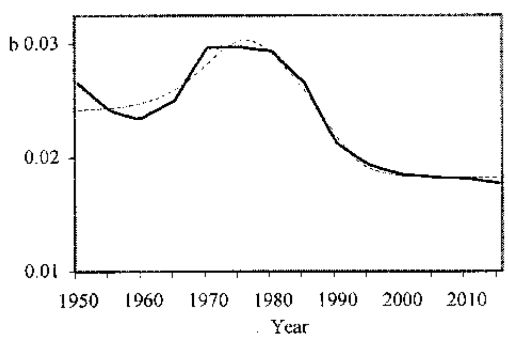


Figure A3 - France "Birth" Rate, 1950-2015
(youngest cohort as percent of adult population)

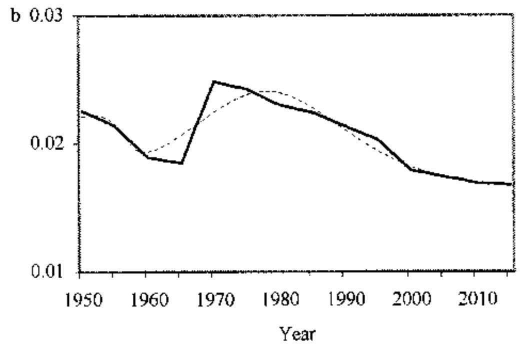


Figure A4 - Italy "Birth" Rate, 1950-2015
(youngest cohort as percent of adult population)

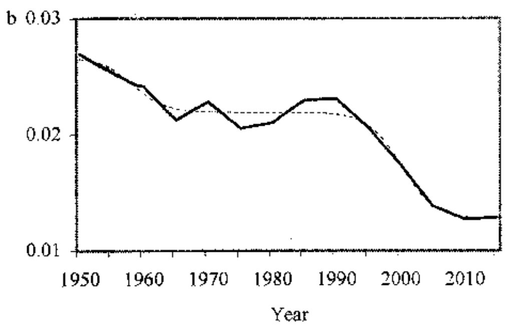


Figure A5 - Japan "Birth" Rate, 1950-2015
(youngest cohort as percent of adult population)

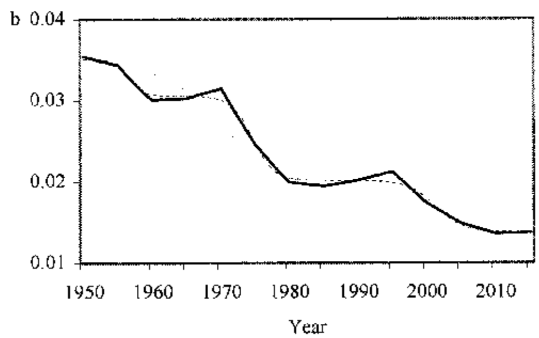
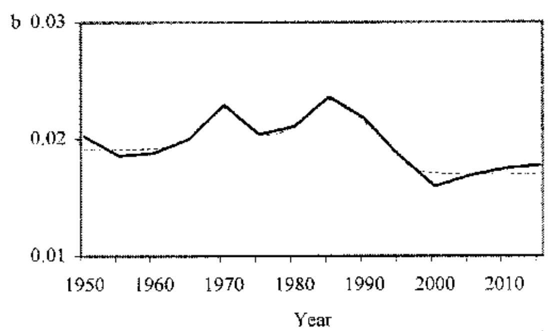


Figure A6-United Kingdom "Birth" Rate, 1950-2015
(youngest cohort as percent of adult population)



Dealing with Common Death Rates

This appendix examines the implications of the simplifying assumption of a common death rate, i.e., that is independent of age.

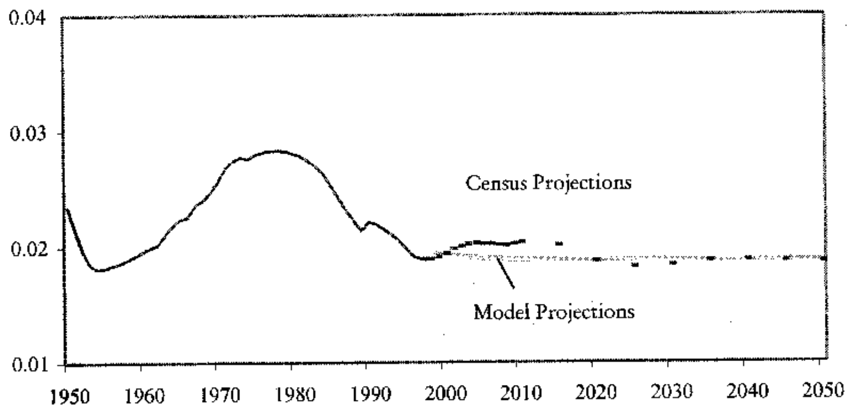
To allow for aggregation in the model, we assume a *common* death or hazard rate across all age groups. This means that the same proportion of each group, and hence the entire population, die in a given period. Though one can vary the death rate over time, since the same fraction applies to all cohorts, changes in the common mortality rate have minimal *distributional* impact on the population age structure, but can have an important aggregative impact by affecting the rate of population growth.

For the demographic projections, this common hazard rate assumption affects the projections of the model compared to more sophisticated demographic projections (e.g., U.S. Census). To quantify how large the differences can be, we reexamine the case of the United States. Based on the empirical specification for the U.S. birth rate–equation (15)—the long-term projections of the birth rate from the model are shown in figure A7 compared to U.S. Census. The death rates used in the model projections are those that are needed implicitly to attain the same rate of population growth (i.e., $b - p = n$) as in the Census projections. So while the projections for population growth coincide, the implications for the dependency ratio in figure A8 show some discrepancy.

In particular, assuming that the old die at the same frequency as the young would tend to *overstate* the share of elderly in the economy by understating the true mortality rate for this group.[40] To compensate, the birth rate can be adjusted upward, thereby increasing the inflow or arrival rate of young people into the economy. An equal adjustment in the death rate would then allow the model to match both the growth and distributional projections with the U.S. Census. In the case of the United States, a half percentage point increase in the birth rate brings the model's projections back in line with the census projection. This same adjustment factor is used for the other industrial countries in generating the projections for the elderly dependency ratio in figure 2.

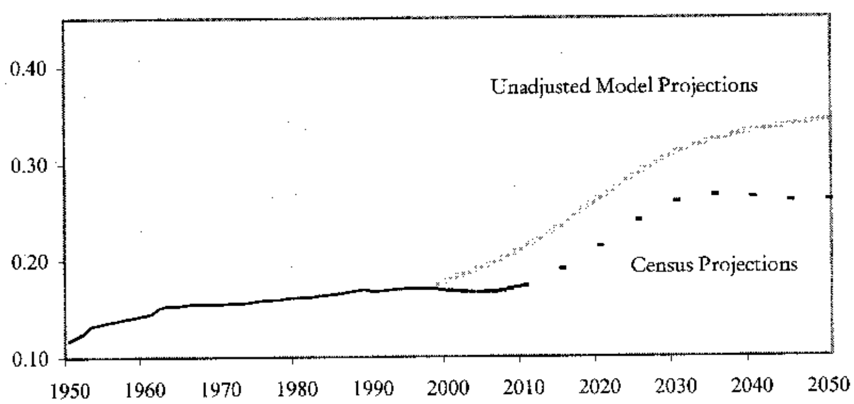
[40]Faruqee (2001) develops an extended version of the Blanchard model with age-specific mortality rates. Compared to this model with realistic mortality rates, the "perpetual youth" or common death rate model is shown to exhibit a significant right tail to the age distribution.

Figure A7: "Birth" Rate, United States
Historical and Projected Series



Data Source: U.S. Bureau of Labor Statistics, U.S. Census Bureau, and Staff estimates.

Figure A8: Elderly Dependency Ratio, United States
Historical and Projected Series



Data Source: U.S. Bureau of Labor Statistics, U.S. Census Bureau, and Staff estimates

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