Demographics and Real Interest Rates Across Countries and Over Time

(Preliminary version)*

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Abstract

We explore the implications of demographic trends for the evolution of real interest rates across countries and over time. To that end, we first develop a tractable three-country general equilibrium model with imperfect capital mobility and country-specific demographic trends. We calibrate the model to study how low-frequency movements in a country's real interest rate depends on its own demographics and on global factors, given a certain degree of financial integration. The more financially integrated a country is, the higher the sensitivity of its real interest rate to global developments, and the less its own real rate determinants matter. We then estimate panel error-correction models relating real interest rates to possible determinants—demographics included—imposing some restrictions motivated by lessons from the structural model. Our empirical evidence supports a meaningful role for life expectancy in determining real interest rates.

JEL codes: E52, E58, J11

Keywords: Life expectancy, population growth, demographic transition, real interest rate, imperfect capital mobility, capital flows, Secular Stagnation

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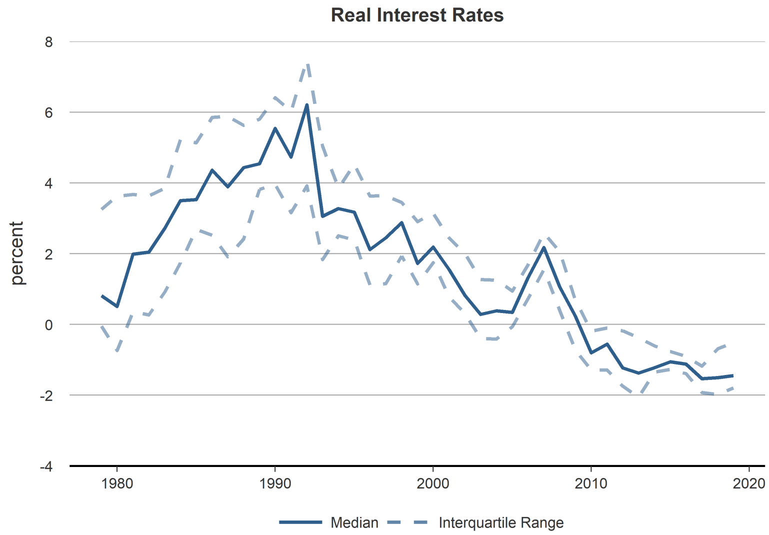
Figure 1: Real interest rates.



Note: Median and interquartile range of ex-ante real short-term interest rates for 19 OECD countries between 1980 and 2019. See section 4 for details about the calculations.

1 Introduction

Real interest rates have been trending down for about three decades across many countries (Figure 1). The current environment of near-zero real interest rates presents several policy challenges and possible opportunities. For example, central banks may have limited space to provide accommodation in the face of a recession. Conversely, fiscal authorities may have strong incentives to increase their borrowing given the low cost in terms of real resources. A crucial dimension for these decisions is understanding whether low real interest rates are only a temporary phenomenon, or are here to stay.

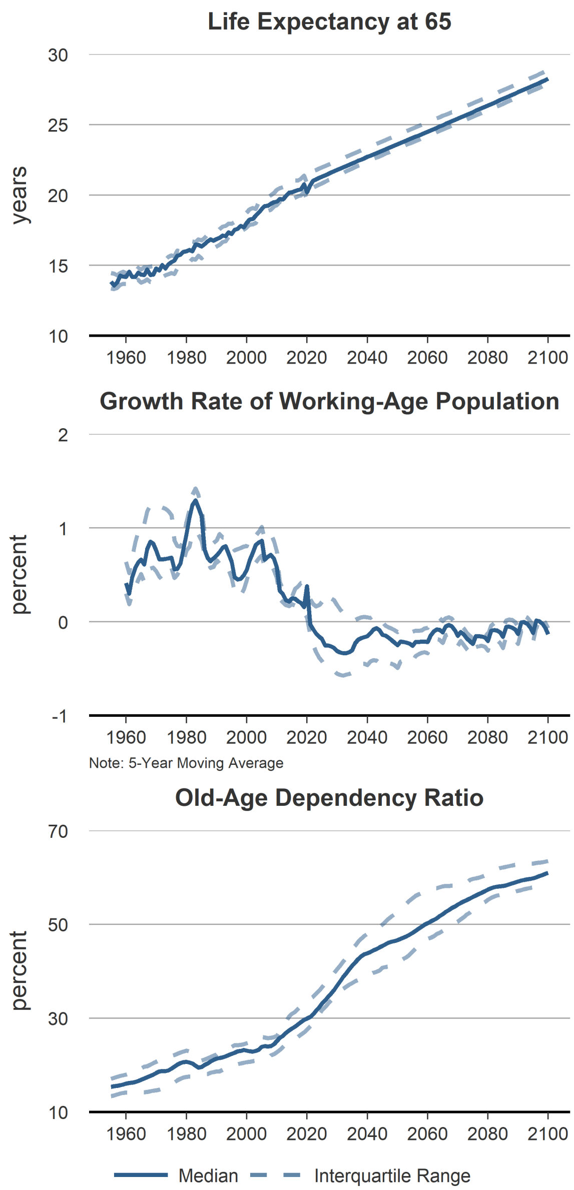
The low-frequency nature of real interest rate developments suggests that structural (long-term) forces are at play.[1] In this paper, we focus on the connection between one long-term force—demographic trends—and the decline of real interest rates.

The data clearly show that advanced economies are aging at a fast pace. Life expectancy at birth has increased by about 10 years between 1960 and 2010 (top panel of Figure 2), while older generations have also experienced longevity gains. At the same time, population growth rates have been sharply declining (middle panel of Figure 2). The result has been a significant increase in the (old) dependency ratio—*i.e.* the ratio between people 65 years and older and people 15 to 64 years old (bottom panel of Figure 2).

Building on our earlier work (Carvalho et al., 2016), we show that past demographic developments and available projections can explain a significant portion of the real interest rate drop observed in in the last three decades. The key contribution of this paper is to confront the demographics-based explanation of

[1] Rachel and Smith (2017), for example, conclude that most of the candidate explanations for persistently low real rates are likely to be permanent. The debate in the literature, however, is far from being one-sided. At the other end of the spectrum, Hamilton et al. (2015) find little evidence of permanent factors in the decline in global real interest rates. Their empirical findings attribute the decline to temporary factors, including deleveraging, tighter financial regulation, and inflation trends.

Figure 2: Demographic variables.



Note: Top panel: Remaining years of life expectancy at 65. Center panel: Five-year moving average of working-age population growth rate. Bottom panel: Number of people 65 and older relative to the number of people 15 to 64 years old. Sample: 19 OECD countries between 1960 and 2100 (projections after 2020). Source: United Nations World Population Prospects (2021 Revision).

low real interest rates with the open economy dimension. If demographics are indeed an important driver of low-frequency movements in real rates, we should expect to see patterns in real interest rates across countries and over time that accord with the relevant demographic developments. That assessment is, however, complicated by at least two issues. First, other factors may affect real rates, so that uncovering the role of any given driver requires carefully controlling for many other potential explanations. Second, in a world with at least some capital mobility, a country's real rate should depend not only on its own demographic developments, but on global factors as well.

To handle these two issues, we resort to both quantitative theory and econometric analysis. We begin by developing a three-country life-cycle model in which households can invest in both domestic and foreign assets. The latter generate portfolio holding costs that proxy for various factors that hinder capital flows in the real world, and lead to imperfect capital mobility in the model.[2] In the model, demographic trends affect the equilibrium real interest rate through three main channels: changes to life expectancy, growth rate of the labor force, and a population composition effect. Importantly, because households can trade assets internationally, demographic developments in one country affect the other as well.

The calibrated model captures salient features of the demographic transition in developed economies. We use this framework to study the low-frequency relationship between demographics and real rates across countries and over time, and how the degree of financial integration shapes this relationship over time. In particular, we focus on how a country's real interest rate depends on its own demographics and on global factors, for different degrees of financial integration. We find that the more financially integrated a country is, the higher the sensitivity of its real interest rate to global developments is, and the less its own real rate determinants matter.

Drawing on the lessons from the model, we then turn to an empirical analysis of the long-run relationship between demographics and real rates. To that end, we estimate panel error-correction models relating real interest rates to demographics and other possible determinants of real rates. Consistently with our theoretical model, we control for global factors through a measure of the relevant global real interest rate faced by each country, and interact countries' possible real rate determinants with a measure of their degree of financial integration. The global rate is always highly significant. Among the domestic factors, demographic variables, and in particular life expectancy, are significant in several specifications.

Our paper belongs to a recent wave of research that investigates, both theoretically and empirically, the determinants of real interest rates. A number of existing contributions focus on demographics, calibrating overlapping generation models to individual economies, such as the U.S. (Gagnon et al., 2016), the euro area (Kara and von Thadden, 2016), and Japan (Ikeda and Saito, 2014).[3] Our focus on the open economy dimension is closer in spirit to Lisack et al. (2017) and, especially, Krueger and Ludwig (2007), who also discuss the interaction between demographics and financial integration. A key difference relative to our paper is that they consider only the two extreme cases of closed economies or fully-integrated capital markets. Nevertheless, we reach similar conclusions as far as real rate predictions are concerned.

Empirically, Lunsford and West (2019) conclude that demographic variables can explain some of the variability of US real interest rates over more than one hundred years, while Fiorentini et al. (2018) highlight the importance of the share of young workers to account for the rise and fall of real rates between 1960 and 2016. Our empirical analysis expands on this latter contribution by pursuing an econometric specification that is informed by our structural model and considering a number of additional candidate

[2]The limiting cases of the two-country version of our model with zero and infinite portfolio costs correspond to Ferrero (2010) and Carvalho et al. (2016), respectively.

[3]Demographic variables feature prominently also among the factors that can explain the secular stagnation hypothesis (Eggertsson et al., 2019). Goodhart and Pradhan (2017) express a contrarian view, arguing that demographic trends will contribute to revert recent observed macroeconomic trends, including for real interest rates.

explanations, such as the role of safe assets (Caballero et al., 2017), productivity growth (Holston et al., 2017), and fiscal variables (Rachel and Smith, 2017). Despite this additional set of potential drivers, demographic variables—in particular, life expectancy—remain a key determinant of real interest rates in many specifications of our panel analysis.

In our model, the real interest is the return on both government bonds, physical capital, and private claims. In practice, these returns differ. As Gomme et al. (2015) have documented for the US, while the return on safe assets (primarily government bonds in advanced economies) has declined, the return on risky assets (in particular equity) has remained roughly constant. Reis (2022) finds that this result is robust across countries, and also to different measures of capital and income. By abstracting from aggregate uncertainty and imperfect competition, our model fails to capture the rise of macroeconomic risk and markups that Farhi and Gourio (2018) and Eggertsson et al. (2021) argue are key drivers of the wedge between the return on equity and the return on government bonds.[4] Therefore, we focus on the comparison between the real interest rate in the model with the return on government bonds in the data.

The rest of the paper proceeds as follows. Section 2 presents the model and exercises that draw implications for how the relationship between demographics and real rates varies with countries' degrees of financial integration. Section 4 presents our empirical analysis and Section 5 concludes.

2 The Model

This section presents an open economy life-cycle model with imperfect capital mobility. Building on Gertler (1999), we allow for time-varying differential demographic trends across countries. Portfolio-holding costs, as in Chang et al. (2015), hamper the free flow of capital across countries. The resulting framework nests the closed economy model of Carvalho et al. (2016) and the open-economy model of Ferrero (2010) as special cases.

2.1 Demographics

The economy consists of $\mathcal{M}$ regions. In each country $m = 1, \ldots, \mathcal{M}$, $(1 - \omega_{mt} + n_{mt})N^w_{mt-1}$ new workers (w) are born in every period t, where N^w_{mt-1} is the number of workers at time $t-1$ and ω_{mt} is the probability a worker remains in the labor force between periods $t-1$ and t. Therefore, the number of workers evolves according to

$$N^w_{mt} = (1 - \omega_{mt} + n_{mt})N^w_{mt-1} + \omega_{mt}N^w_{mt-1} = (1 + n_{mt})N^w_{mt-1},$$

so that n_{mt} is the net growth rate of the labor force.

A worker who exits the labor force becomes a retiree (r). The probability of a retiree surviving

[4] In addition, Farhi and Gourio (2018) also find a role for the rising importance of intangibles in production.

between periods $t-1$ and t is γ_{mt}. Therefore, the number of retirees evolves according to

$$N_{mt}^{r} = (1-\omega_{mt})N_{mt-1}^{w} + \gamma_{mt}N_{mt-1}^{r}.$$

The (old) dependency ratio, $\psi_{mt} \equiv N_{mt}^{r}/N_{mt}^{w}$, measures the number of retirees per worker, and evolves according to

$$(1+n_{mt})\psi_{mt} = (1-\omega_{mt}) + \gamma_{mt}\psi_{mt-1}. \tag{1}$$

The growth rate of the labor force and the probability of surviving as a retiree are the fundamental demographic variables in the model. In our quantitative exercises, we will measure the growth rate of the labor force directly from the data. Conditional on a given retirement age, we will back out the probability of surviving from the evolution of the (old) dependency ratio, which is an observable variable, using equation (1).

2.2 Preferences

Retirees and workers value consumption streams according to recursive non-expected utility preferences (Epstein and Zin, 1989)

$$V_{mt}^{z} = \max\left[(C_{mt}^{z})^{\frac{\sigma-1}{\sigma}} + \beta_{mt+1}^{z}\mathbb{E}_t\left[V_{mt+1}^{1-\theta}|z\right]^{\frac{\sigma-1}{\sigma(1-\theta)}}\right]^{\frac{\sigma}{\sigma-1}},$$

where $z = \{w, r\}$ represents the agent's type, V_{mt}^{z} represents the value of utility for an agent of type z at time t, C_{mt}^{z} denotes consumption of the single good, $\sigma > 0$ is the elasticity of intertemporal substitution, and θ is the coefficient of risk aversion. The discount factor $\beta_{mt+1}^{z} > 0$ differs between retirees and workers:

$$\beta_{mt+1}^{z} = \begin{cases} \beta_m & \text{if } z = w \\ \\ \beta_m\gamma_{mt+1} & \text{if } z = r. \end{cases}$$

With standard preferences (e.g. constant relative risk aversion), the assumption that the transition probability into retirement is independent of age would give rise to excessive precautionary savings early in life. To mitigate this effect while retaining the sensitivity of consumption decisions to changes in the interest rate, we assume risk neutrality with respect to income fluctuations ($\theta = 0$).[5]

[5] The resulting preferences imply linear consumption decisions (Farmer, 1990), thus facilitating aggregation among workers and retirees of different ages.

2.3 Retirees

The problem of a retiree from country m born in period j and retired in period k is

$$V_{mt}^{rjk} = \max_{C_{mt}^{rjk}, \left\{A_{m\ell t}^{rjk}\right\}_{\ell=1}^{\mathcal{M}}} \left[\left(C_{mt}^{rjk} \right)^{\frac{\sigma-1}{\sigma}} + \beta_m \gamma_{mt+1} \left(V_{mt+1}^{rjk} \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{2}$$

subject to

$$C_{mt}^{rjk} + \left[1 + \sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2} \left(\eta_{m\ell t}^{rjk} - \bar{\eta}_{m\ell} \right)^2 \right] \sum_{\ell=1}^{\mathcal{M}} A_{m\ell t}^{rjk} = \frac{1}{\gamma_{mt}} \sum_{\ell=1}^{\mathcal{M}} R_{\ell t-1} A_{m\ell t-1}^{rjk} + E_{mt}^{rjk}, \tag{3}$$

where $\eta_{m\ell t}^{rjk} \equiv A_{m\ell t}^{rjk} / (\sum_{p=1}^{\mathcal{M}} A_{mpt}^{rjk})$ are portfolio shares, $A_{m\ell t}^{rjk}$ are assets that a retiree of country m holds against country $\ell = 1, \ldots, \mathcal{M}$ and pay a gross return is $R_{\ell t}$. At the beginning of each period, retirees turn their wealth to a perfectly competitive mutual fund that pools the risk of death and pays an extra return equal to the inverse of the survival probability, as in Yaari (1965) and Blanchard (1985). In addition, a retiree receives a lump-sum pension benefit E_{mt}^{rjk} from the government. In forming their portfolios, retirees incur a cost that depends on the difference between the actual share invested in foreign assets $\eta_{m\ell t}^{rjk}$ and an exogenous target level $\bar{\eta}_{m\ell}$ that we assume to be independent of type and that pins down steady state gross foreign asset positions.[6] Following Chang et al. (2015), we assume that portfolio-holding costs are quadratic, and that their level depends on a time-varying parameter $\Lambda_{m\ell t} \geq 0$. By limiting capital flows across countries, portfolio costs capture, in reduced form, all the factors that prevent equalization of real interest rates across countries, even after controlling for risk premia.[7] One interpretation of our adjustment cost formulation is that retirees delegate their investment to portfolio managers who charge a fee to invest in foreign assets.[8]

Appendix A.1 shows that the share a retiree invests in country-p assets (with $p \neq m$) is independent of age and time since retirement ($\eta_{mpt}^{rjk} = \eta_{mpt}^{r}$, $\forall j$ and k), and satisfies

$$\left[1 + \sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2} \left(\eta_{m\ell t}^{r} - \bar{\eta}_{m\ell} \right)^2 \right] (R_{pt} - R_{mt}) = \Lambda_{mpt} \left(\eta_{mpt}^{r} - \bar{\eta}_{mp} \right) R_{mt}. \tag{4}$$

In addition, Appendix A.2 shows that the same condition holds for workers. Therefore, retirees and workers invest the same share of their total financial wealth in country-p assets ($\eta_{mpt}^{r} = \eta_{mpt}^{w} = \eta_{mpt}$).

The solution of the optimization problem for a retiree yields a consumption function linear in the sum

[6] The portfolio cost "rate" is positive as long as the share of foreign assets deviates from $\bar{\eta}_{mn}$. The assumption that this cost rate applies to total assets keeps the model tractable, allowing us to make substantial analytical progress based on a guess-and-verify approach.

[7] When $\Lambda_{m\ell t}$ tends to infinity, the countries in the model become closed, as in Carvalho et al. (2016). Conversely, when these parameters are equal to zero, the model corresponds to a multi-country version of Ferrero (2010).

[8] In our formulation, the government collects the costs so we can think of government regulation limiting foreign financial investment. Alternatively, we could write these costs in terms of real resources, possibly devoted to research about foreign financial markets.

of total financial wealth and the present discounted value of pension benefits (S^{rjk}_{mt}):

$$C^{rjk}_{mt} = \xi^r_{mt} \left(\frac{1}{\gamma_{mt}} \sum_{\ell=1}^{\mathcal{M}} R_{\ell t-1} A^{rjk}_{m\ell t-1} + S^{rjk}_{mt} \right), \tag{5}$$

where

$$S^{rjk}_{mt} = E^{rjk}_{mt} + \frac{\gamma_{mt+1} S^{rjk}_{mt+1}}{\tilde{R}_{mt}},$$

and where we have defined the adjusted gross return

$$\tilde{R}_{mt} \equiv \frac{\sum_{\ell=1}^{\mathcal{M}} \eta_{m\ell t} R_{\ell t}}{1 + \sum\limits_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2} (\eta_{m\ell t} - \bar{\eta}_{m\ell})^2}. \tag{6}$$

The marginal propensity to consume is also independent of individual characteristics (birth and retirement age), and evolves according to the Euler equation

$$\frac{1}{\xi^r_{mt}} = 1 + \gamma_{mt+1} \beta^\sigma_m \tilde{R}^{\sigma-1}_{mt} \frac{1}{\xi^r_{mt+1}}. \tag{7}$$

2.4 Workers

In every period, workers need to take into account the possibility of retirement. Thus, with probability ω_{mt+1}, the continuation value for an individual born in period j and currently employed is V^{wj}_{mt+1}, and is V^{rjt+1}_{mt+1} with the complementary probability. The full optimization problem is

$$V^{wj}_{mt} = \max_{C^{wj}_{mt}, \{A^{wj}_{m\ell t}\}^{\mathcal{M}}_{\ell=1}} \left\{ \left(C^{wj}_{mt} \right)^{\frac{\sigma-1}{\sigma}} + \beta_m \left[\omega_{mt+1} V^{wj}_{mt+1} + (1 - \omega_{mt+1}) V^{rjt+1}_{mt+1} \right]^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}}, \tag{8}$$

subject to

$$C^{wj}_{mt} + \left[1 + \sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2} \left(\eta^{wj}_{m\ell t} - \bar{\eta}_{m\ell} \right)^2 \right] \sum_{\ell=1}^{\mathcal{M}} A^{wj}_{m\ell t} = \sum_{\ell=1}^{\mathcal{M}} R_{\ell t-1} A^{wj}_{m\ell t-1} + W^w_{mt} - T^w_{mt}, \tag{9}$$

where W^w_t is the real wage and T^w_{mt} are lump-sum taxes, which only workers pay.[9]

As already mentioned, all workers optimally choose the same portfolio shares, which also equal the choice of retirees. Workers' consumption is linear in the sum of total financial wealth, human wealth, and

[9] As in Ferrero (2010) and Carvalho et al. (2016), we assume that workers inelastically supply one unit of labor and that retirees do not work. Gertler (1999) shows how to relax both these assumptions. With endogenous labor, the optimal response to a declining growth rate of the labor force and an increase in life expectancy would be to supply more hours. Such a behavior of hours worked would be inconsistent with the data for most OECD economies (OECD, 2018).

the present discounted value of pension benefits:

$$C_{mt}^{wj} = \xi_{mt}^{w} \left(\sum_{\ell=1}^{\mathcal{M}} R_{\ell t-1} A_{m\ell t-1}^{wj} + H_{mt}^{wj} + Z_{mt}^{wj} \right), \tag{10}$$

where human wealth is

$$H_{mt}^{wj} = W_{mt}^{w} - T_{mt}^{w} + \frac{\omega_{mt+1} H_{mt+1}^{wj}}{\Omega_{mt+1} \tilde{R}_{mt}},$$

and the present discounted value of pension benefits for workers is

$$Z_{mt}^{wj} = \frac{1}{\Omega_{mt+1} \tilde{R}_{mt}} \left[(1 - \omega_{mt+1}) \left(\frac{\xi_{mt+1}^{r}}{\xi_{mt+1}^{w}} \right)^{\frac{1}{1-\sigma}} S_{mt+1}^{rjt+1} + \omega_{mt+1} Z_{mt+1}^{wj} \right].$$

Workers discount both variables by the adjusted gross return (6) times an additional factor that takes into account the probability of retiring and the heterogeneity in the marginal propensity to consume between the two groups:

$$\Omega_{mt} \equiv \omega_{mt} + (1 - \omega_{mt}) \left(\frac{\xi_{mt}^{r}}{\xi_{mt}^{w}} \right)^{\frac{1}{1-\sigma}}. \tag{11}$$

Because retirees and workers discount the future at different rates, Ricardian equivalence does not hold in this model, even though taxes are lump-sum.

Finally, as for retirees, the marginal propensity to consume for workers is independent of individual characteristics and evolves according to

$$\frac{1}{\xi_{mt}^{w}} = 1 + \beta_{m}^{\sigma} \left(\Omega_{mt+1} \tilde{R}_{mt} \right)^{\sigma-1} \frac{1}{\xi_{mt+1}^{w}}. \tag{12}$$

2.5 Aggregation

Since marginal propensities to consume are independent of individual characteristics and consumption functions are linear, we can aggregate among workers and among retirees by simply adding over individuals in each group.[10]

Aggregate retirees' consumption is given by

$$C_{mt}^{r} = \xi_{mt}^{r} \left(\sum_{\ell=1}^{\mathcal{M}} R_{\ell t-1} A_{m\ell t-1}^{r} + S_{mt}^{r} \right).$$

Note that, in the aggregate, the extra-return the mutual fund offers corresponds to the fraction of retirees who survive between two periods because of the law of large numbers. Similarly, aggregate workers'

[10] In dropping reference to the birth and retirement period, we use the notation $\sum_r C_{mt}^{rjk} = N_{mt}^{r} C_{mt}^{rjk} \equiv C_{mt}^{r}$ and $\sum_w C_{mt}^{wj} = N_{mt}^{w} C_{mt}^{wj} \equiv C_{mt}^{w}$. The same notation applies to asset holdings, human wealth, and the present discounted value of pensions for retirees and workers.

consumption is given by

$$C^w_{mt} = \xi^w_{mt} \left(\sum_{\ell=1}^{\mathcal{M}} R_{\ell t-1} A^w_{m\ell t-1} + H^w_{mt} + Z^w_{mt} \right).$$

Aggregate consumption in country m is simply the sum of retirees' and workers' consumption:

$$C_{mt} \equiv C^w_{mt} + C^r_{mt}.$$

Finally, because of the heterogeneity between workers and retirees over the life cycle, we need to keep track of the distribution of wealth between these two groups. The result that retirees and workers from a given country choose the same portfolio shares is useful in this respect. First, given the total amount of country-n assets held by country-m agents, we define the share held by retirees as

$$\lambda_{mpt} \equiv \frac{A^r_{mpt}}{A^r_{mpt} + A^w_{mpt}}. \tag{13}$$

Second, from the definition of portfolio shares, $A^z_{mpt} = \eta_{mpt} A^z_{mt}$ for $z = \{r, w\}$, where $A^z_{mt} = \sum_{\ell=1}^{\mathcal{M}} A^z_{m\ell t}$. Using this definition in equation (13), we obtain

$$\lambda_{mpt} = \frac{A^r_{mt}}{A^r_{mt} + A^w_{mt}} = \lambda_{mt},$$

that is, the retirees' share of country-p assets held by country-m agents corresponds to the share of wealth accruing to retirees in country m. In appendix A.3, we show that, combining the budget constraints of retirees and workers, we can derive the evolution of the distribution of wealth, which obeys

$$\begin{aligned}\left[1 + \sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell}}{2} \left(\eta_{m\ell t} - \bar{\eta}_{m\ell}\right)^2\right] &[\lambda_{mt} - (1 - \omega_{mt+1})] A_{mt} \\ &= \omega_{mt+1} \left[(1 - \xi^r_{mt}) \lambda_{mt-1} A_{mt-1} \sum_{\ell=1}^{\mathcal{M}} R_{\ell t-1} \eta_{m\ell t-1} + E_{mt} - \xi^r_{mt} S_{mt}\right],\end{aligned} \tag{14}$$

where $A_{mt} \equiv A^r_{mt} + A^w_{mt}$ represents the total amount of assets held by country-m residents.

2.6 Firms

A continuum of measure one of perfectly competitive firms operate in each country. Firms hire workers and accumulate capital K_{mt} to produce the single good according to a labor-augmenting Cobb-Douglas technology, identical across countries:

$$Y_{mt} = \left(X_{mt} N^w_{mt}\right)^{\alpha} K^{1-\alpha}_{mt-1},$$

where $\alpha \in (0,1)$ and Y_{mt} represents output. The productivity factor grows exogenously at a rate x_{mt} between periods $t-1$ and t:

$$X_{mt} = (1 + x_{mt})X_{mt-1}.$$

The law of motion of capital is standard:

$$K_{mt} = (1-\delta)K_{mt-1} + I_{mt},$$

where I_{mt} stands for investment and $\delta \in (0,1)$ is the depreciation rate.

The first order conditions for firms are standard. The wage is equal to the marginal product of labor

$$W_{mt}^{w} = \alpha \frac{Y_{mt}}{N_{mt}^{w}},$$

while the real interest rate is equal to the marginal product of capital

$$R_{mt} = (1-\alpha)\frac{Y_{mt+1}}{K_{mt}} + (1-\delta).$$

2.7 Government

In each period, the government issues one-period bonds, B_{mt}, and levies lump-sum taxes on workers $T_{mt} \equiv N_{mt}^{w} T_{mt}^{w}$ to fund pension benefits $E_{mt} \equiv N_{mt}^{r} E_{mt}^{r}$ and wasteful spending G_{mt}, and to repay maturing debt inclusive of interests to bondholders $R_{mt-1}B_{mt-1}$. The government also collects the amount of resources foreign investors forego to hold positions in country-m assets (the portfolio-holding costs). Its budget constraint is:

$$B_{mt} = R_{mt-1}B_{mt-1} + G_{mt} + E_{mt} - \left[T_{mt} + \sum_{\ell \neq m} \frac{\Lambda_{\ell mt}}{2} (\eta_{\ell mt} - \bar{\eta}_{\ell m})^2 A_{\ell t} \right].$$

We assume that debt, spending, and pensions are exogenous fractions of output:

$$G_{mt} = g_{mt} Y_{mt}, \qquad B_{mt} = b_{mt} Y_{mt}, \qquad E_{mt} = e_{mt} Y_{mt},$$

so that the government budget constraint determines taxes residually.

2.8 Balance of Payments and Equilibrium

Country-m assets held by its residents correspond to the amount of capital and bonds not owned by foreigners:

$$A_{mmt} = K_{mt} + B_{mt} - \sum_{\ell \neq m} A_{\ell mt}.$$

Net foreign assets for country m equal the gross amount of foreign assets owned by its residents net of country-m assets held by foreigners:

$$F_{mt} \equiv \sum_{\ell \neq m} (A_{m\ell t} - A_{\ell m t}).$$

Net foreign assets evolve according to

$$F_{mt} = F_{mt-1} + \sum_{\ell \neq m} (R_{\ell t-1} - 1) A_{m\ell t-1} - (R_{mt-1} - 1) \sum_{\ell \neq m} A_{\ell m t-1} \\ - \sum_{\ell \neq m} \frac{\Lambda_{m\ell t}}{2} \left(\eta_{m\ell t} - \bar{\eta}_{m\ell}\right)^2 A_{mt} + \sum_{\ell \neq m} \frac{\Lambda_{\ell m t}}{2} (\eta_{\ell m t} - \bar{\eta}_{\ell m})^2 A_{\ell t} + NX_{mt},$$

where the trade balance is the difference between production and domestic absorption:

$$NX_{mt} \equiv Y_{mt} - C_{mt} - G_{mt} - I_{mt}.$$

Finally, the global asset market-clearing condition is:

$$\sum_{\ell=1}^{\mathcal{M}} F_{\ell t} = 0.$$

Because the labor force and technology grow over time, we focus on a solution for de-trended variables.[11] Given exogenous processes for the growth rate of the labor force, life expectancy, the growth rate of technology, and fiscal variables, a competitive equilibrium for the world economy requires that, in each country: retirees and workers maximize utility subject to their budget constraints; firms maximize profits given their technological constraints; the government satisfies its budget constraint; and labor markets clear. In addition, the asset market clears at the global level.

We solve the model with an "extended-path" approach, according to which agents form expectations in each period assuming that the exogenous processes will remain constant at their current values into the indefinite future. The extended-path solution concatenates the pointwise equilibrium values obtained in each period by solving for the perfect-foresight path from each period onward under those "constant beliefs." Like perfect foresight, the extended-path approach allows us to obtain a fully non-linear solution for the transition between steady states focusing on low-frequency dynamics (i.e., abstracting from fluctuations that are the focus of business cycle models with aggregate shocks). However, because of the constant-beliefs assumption, the extended-path approach avoids the excessive "front-loading" of responses that characterizes the standard perfect-foresight solution.

[11] For a generic variable D_t, the stationary counterpart is $d_t \equiv D_t/(X_t N_t^w)$. The model admits a well-defined steady state in terms of de-trended variables.

Table 1: Demographic variables in the initial steady state (in %).

Parameter	Young Economy	Old Economy	Rest of the World
Relative size ($N^w_{m0}/N^w_{\mathcal{W}0}$)	0.38	0.38	100
Growth rate of the labor force (n_{m0})	1.13	0.59	0.75
Dependency ratio (ψ_{m0})	20.98	24.46	22.29

3 Quantitative Analysis

Our main quantitative experiment characterizes the macroeconomic transition of the world economy between two steady states driven by differential demographic developments across countries and time-varying degrees of financial integration. For simplicity, we assume that technology and fiscal variables remain constant and equal across countries.

3.1 Calibration

Each period corresponds to one year. We specialize our multi-country model to a world with three regions: a small young economy ($\mathcal{Y}$), a small old economy ($\mathcal{O}$), and the rest of the world ($\mathcal{W}$). The "young" economy has a relatively high growth rate of the labor force and a relatively low dependency ratio, while the opposite is true for the "old" economy. The rest of the world captures the median demographic profile.

The source for the demographic data is the United Nation World Population Database (2019). We assume that the initial size of the rest of the world is equal to the sum of the working-age population across the twenty OECD economies in our sample in 1990 (3.78 billion), and we set the initial relative size of both the young and the old economy to 0.4% to match the first quartile of the cross-sectional distribution of sizes in the same year.

In the initial steady state, the young economy has a relatively high growth rate of the labor force and a relatively low dependency ratio. We target the initial growth rate of the working-age population and the dependency ratio in this region to match the third and first quartile, respectively, of their empirical counterparts, which gives $n_{\mathcal{Y}0} = 1.13\%$ and $\psi_{\mathcal{Y}0} = 20.98\%$. Vice versa, for the old economy, we target the first quartile for the growth rate of the working-age population and the third quartile for the dependency ratio ($n_{\mathcal{O}0} = 0.59\%$ and $\psi_{\mathcal{O}0} = 24.46\%$, respectively). Finally, for the rest of the world, we simply target the weighted average of the countries in our sample for both growth rate of the working-age population and dependency ratio ($n_{\mathcal{W}0} = 0.75\%$ and $\psi_{\mathcal{W}0} = 22.29\%$).[12] Table 1 reports the calibrated values for the demographic variables in the initial steady state.

We follow Gertler (1999) and Carvalho et al. (2016) in setting most of the remaining parameters that

[12] Conditional on the growth rate of the working-age population and on the probability of retiring (which we discuss in the text), the steady state version of equation (1), $\psi_m = (1-\omega)/(1+n_m-\gamma_m)$, provides a unique mapping between the dependency ratio of country m and a value for its probability of surviving.

Table 2: Common parameters across countries.

Parameter value			Description
ω	$=$	0.978	Average employment duration
σ	$=$	0.500	Elasticity of intertemporal substitution
α	$=$	0.667	Labor share
δ	$=$	0.100	Depreciation rate
x	$=$	0.005	Growth rate of productivity
$\bar{\eta}$	$=$	0	Steady state net foreign asset position
b	$=$	0.600	Debt/GDP
g	$=$	0.250	Government spending/GDP
e	$=$	0.075	Pensions/GDP

are common to all countries (Table 2). Agents are born workers at the age of 20. We fix the probability of remaining employed ω at 0.978 to match an average employment duration of 45 years so that on average individuals retire at 65. We set the elasticity of intertemporal substitution σ to 0.5, consistent with the evidence in Hall (1988) and Yogo (2004), who report values significantly lower than one. We further set the labor share α equal to 0.667 and the depreciation rate δ equal to 0.1, which are standard values in the literature. We assume that the growth rate of technology is $x = 0.5\%$, roughly in line with the average growth rate for the countries in our dataset since 1990. We calibrate fiscal variables (debt, government spending and pensions) as a fraction of GDP to match the average values for OECD countries since 1990, which implies $b = 60\%$, $g = 25\%$ and $e = 7.5\%$, respectively.

The remaining parameters to calibrate are the target shares for foreign asset holdings, the initial value of the portfolio holding costs and the individual discount factors. For simplicity, we assume the target shares for foreign asset holdings $\bar{\eta}$ to be zero in all countries.[13] Finally, for each country, we jointly choose the initial value of the portfolio-holding cost parameter $\Lambda_{mn0}(= \Lambda_{nm0})$ and of the individual discount factor β_m to target the real interest rate and the external position in the initial steady state. The real interest rate measure that we use is a three-year moving average centered in 1990 of the ex-ante short yield (the same data plotted in Figure 1). For the external position, we target the cross-country distribution of gross foreign debt relative to GDP from Lane and Milesi-Ferretti (2017). The focus on debt aligns well our real interest rate measure with the appropriate asset class in the data. While the model only keeps track of net foreign assets, we use the gross position as the empirical asset measure to limit the heterogeneity in discount factors necessary to match the initial dispersion of real interest rates. For the young economy, we match the third quartile of the empirical distribution of real interest rates (7.01%) and the first quartile of the gross foreign debt liabilities relative to GDP (39.36%), which gives $\beta_{\mathcal{Y}} = 0.987$, $\Lambda_{\mathcal{YO}0} = 300$ and $\Lambda_{\mathcal{YW}0} = 32.8595$.[14] Similarly, for the old economy, we match the

[13] In spite of the target, however, the foreign asset position in the initial steady state actually differs from zero because of the cross-country demographic differences.

[14] The high value for $\Lambda_{\mathcal{YO}0} = \Lambda_{\mathcal{OY}0}$ is a by-product of the calibration strategy. A high value of the portfolio-holding cost parameter corresponds to a country being in autarky. Starting from autarky, we then progressively lower the friction

Table 3: Discount factors and portfolio-holding costs.

Parameter	Young Economy	Old Economy	Rest of the World
Discount factor (β_m)	0.987	1.013	1.003
Portfolio holding costs ($\Lambda_{\mathcal{Y}n0}$)	0	300	32.8595
Portfolio holding costs ($\Lambda_{\mathcal{O}n0}$)	300	0	68.5684
Portfolio holding costs ($\Lambda_{\mathcal{W}n0}$)	32.8595	68.5684	0

first quartile of the distribution of real interest rates (3.56%) and the first quartile of gross foreign debt assets relative to GDP (16.79%), which gives $\beta_{\mathcal{O}} = 1.013$ and $\Lambda_{\mathcal{O}\mathcal{W}0} = 68.5684$. Finally, for the global economy, we match the median real interest rate (5.28%) and a balanced external position, which gives $\beta_{\mathcal{W}} = 1.003$.[15] Table 3 summarizes this part of the calibration.

3.2 Experiment

In our baseline experiment, the size of the three economies and the degree of financial integration evolve endogenously over time in response to the evolution of the demographic variables and to changes of the portfolio-holding cost parameters. The targets for these variables are the same as for the steady state (growth rate of working-age population, dependency ratio, and gross foreign debt positions relative to GDP). In order to focus on the low frequency movements of demographic variables and financial integration, we feed the model with the trend component of a HP filter (Hodrick and Prescott, 1997) applied to the data (see Figure 3).[16] Due to the limited availability of the data for foreign debt, we consider the period 1990-2020 as our "sample." The simulation, however, uses the projected trends for demographic variables and foreign debt until 2070. We refer to the results for the period 2021-2070 as "projections."

3.3 Results

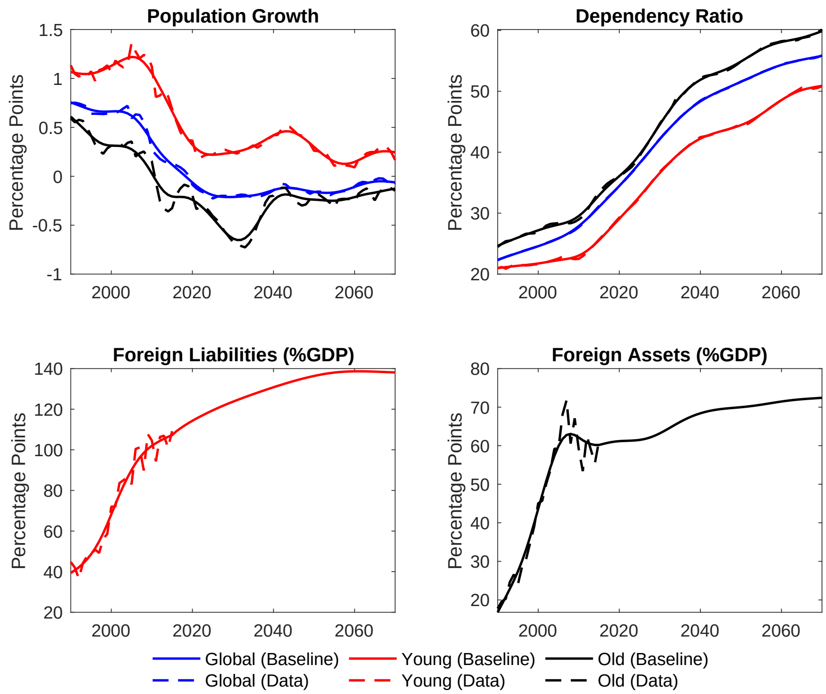
Figure 4 shows the results of the basic experiment for the period 1990-2070. In sample (1990-2020), the real interest rate of the global economy (solid blue line) falls by about two percentage points, from its initial value of 5.28% to 3.10%. In the young economy, the decline is almost three percentage points (from 7% to 4.15%). Over the entire sample, the interest rate falls also in the old economy, by about one and a half percentage point (from 3.56% to 2.19%). However, differently from the other two countries, the dynamics are not monotone in this case. Before starting to decline, the real interest rate actually increases for the first decade and a half of the sample to reach almost 4%. **[AF: Check exact numbers]**

to match the target for the gross foreign debt position. Given the relative size of the three countries, the bulk of financial flows occurs between each small country and the global economy so that we can simply adjust the portfolio holding cost parameter $\Lambda_{m\mathcal{W}0}$.

[15] The household problem is well defined even when the individual discount factor is bigger than one as long as $\beta_m \gamma_{mt} < 1$, which is always the case in our experiments.

[16] The smoothing parameter for both the demographic variables and the financial integration is 40.

Figure 3: Calibration of demographic processes and financial integration.

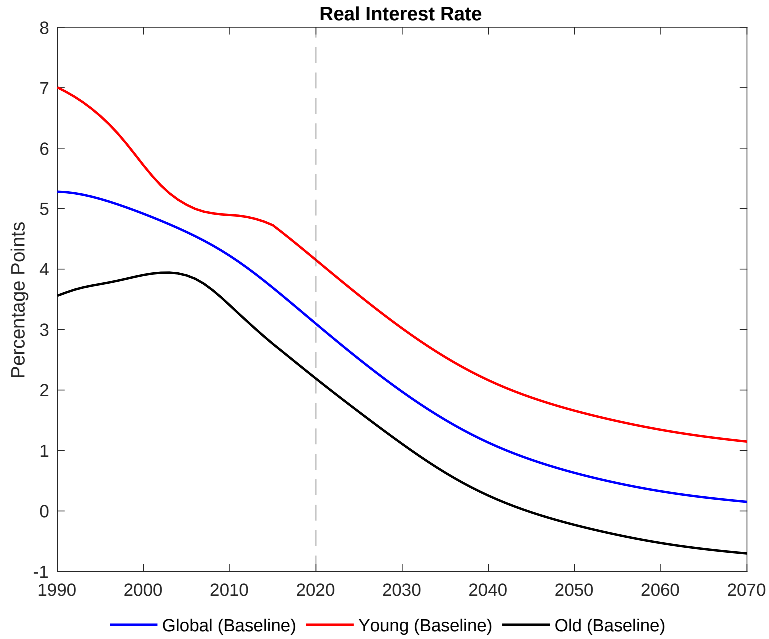


Note: Growth rate of working-age population (top-left panel), dependency ratio (top-right panel), foreign debt liabilities (bottom-left), and foreign debt assets (bottom-right). Red lines correspond to the young economy, black lines to the old economy, blue lines to the rest of the world. The dashed lines are data, the solid lines are the fitted processes (trend from a HP filter).

These rich dynamics reflect the interaction between demographic variables and financial integration. In general, the evolution of demographic variables exerts downward pressure on the real interest rate. As countries move towards full financial integration, real interest rates across countries converge. Given the respective starting points, the real interest rate falls in the young economy but increases in the old economy. The dynamics of foreign debt liabilities as a percentage of GDP (red line in Figure 3) suggest that the process of financial integration has slowed down following the financial crisis of 2008. Even more strikingly, foreign debt assets as a percentage of GDP fell slightly (black line in Figure 3), thus determining the divergence of real interest rates for both small regions relative to the global economy in the last few years of the sample .

Going forward, the projections for demographic variables by the United Nations suggest that the aging process will continue everywhere in the world, with some further decline in the growth rate of the labor force and a progressive increase in the dependency ratio. The implication is that real interest rates will continue to decline, reaching a level near zero globally in 2070. As for financial integration, we can only assess the evolution of foreign debt assets and liabilities based on the projected trends from our filtering procedure, which imply a further increase in liabilities and a stabilization of assets. The model predicts that the dispersion of about one percentage point on each side of the global real interest rate prevailing

Figure 4: Real interest rates in the baseline simulation.



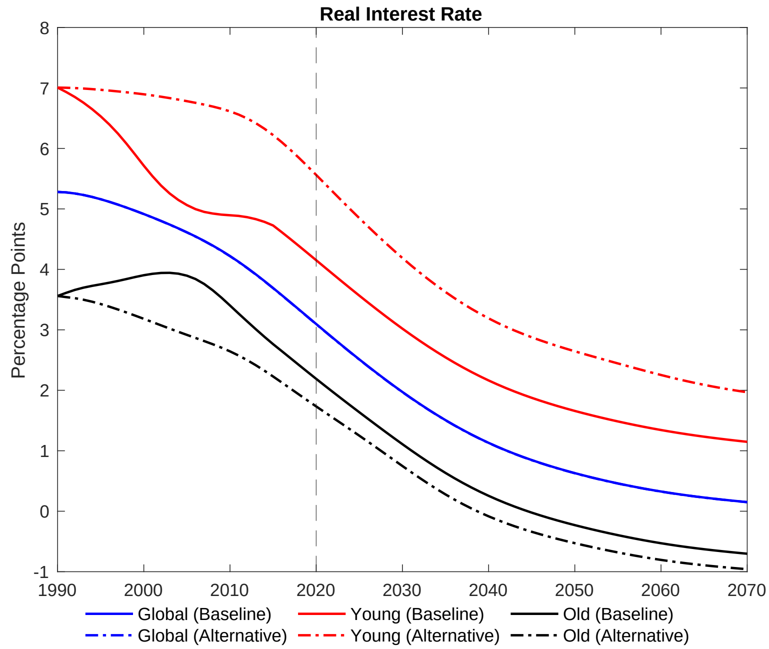
Note: The figure plots the simulated real interest rate from the model (baseline experiment) for the global economy (blue line), the young economy (red line), and the old economy (black line). The vertical line denotes the last period for which data on foreign debt are available.

in 2020 will persist throughout the simulation horizon. Should financial integration experience a further boost in the future, real interest rates will converge once again, as we observed especially between 1990 and 2005.

[AF: The numbers of the most recent figure do not seem consistent with the figures in the calibration report.]

Figure 5 isolates the role of financial integration in determining the dynamics of real interest rates across regions. The solid lines are again the real interest rate in the three regions from the baseline experiment. The dashed-dotted lines correspond to the simulation that keeps the degree of financial integration at its initial value. Because the size of the three regions changes over time, in the counterfactual we adjust the friction so that in each period we match the same target for foreign debt assets and liabilities as in the initial steady state. Not surprisingly, financial integration does not matter for the global economy. The real interest rate is essentially unchanged in the two cases for country $\mathcal{W}$, to the extent that the results from the two simulations are virtually indistinguishable. Conversely, financial integration makes a big difference for the two small economies. As discussed, the evolution of demographic variables still exerts downward pressure on the real interest rate in both regions. In line with the closed economy results in Carvalho et al. (2016), the decline is less pronounced in country $\mathcal{Y}$ and more so in country $\mathcal{O}$. The main difference with the baseline simulation is that, with constant financial integration, the real interest rate

Figure 5: Real interest rates with constant financial integration.



Note: The figure plots the simulated real interest rate from the model for the global economy (blue lines), the young economy (red lines), and the old economy (black lines). The solid lines correspond to the baseline simulation. The dashed-dotted lines are the counterfactual simulation in which the degree of financial integration remains at its initial value.

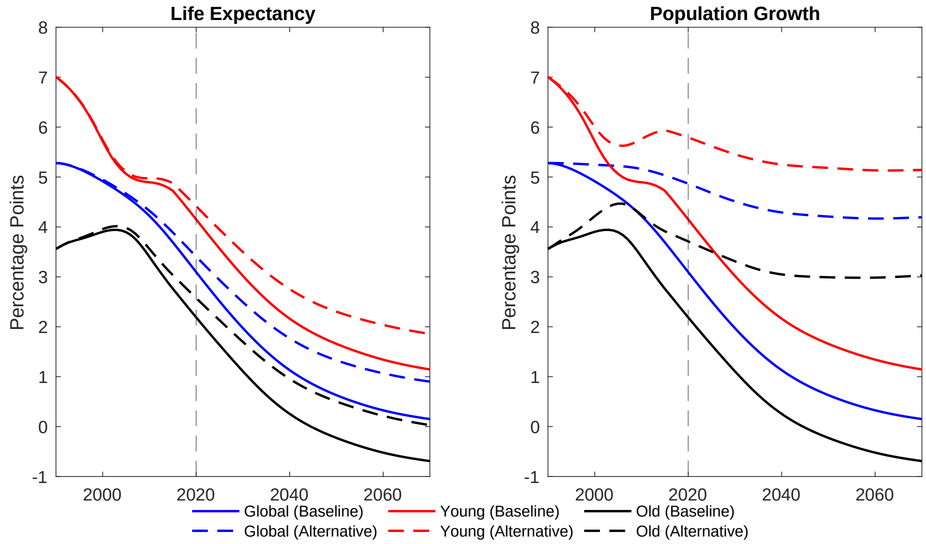
of the old economy now falls monotonically, and also by more. As a result, the real interest rates in the two small economies do not converge (in fact diverge slightly). With constant financial integration, domestic demographic developments dominate. Conversely, with increasing financial integration, global demographic trends become progressively more important over time.

The dashed-dotted lines in Figure 6 show the path of the real interest rate in the three regions in two counterfactual simulations. The left panel presents the result of the simulation in which we fix the growth rate of the working-age population at its initial value. The right panel displays the experiment in which we hold the probability of surviving constant at its initial value. The increase in life expectancy associated with the higher probability of surviving explains about 4/5 of the overall effect, depending on the region. Conversely, the lower growth rate of the labor force explains less than 1/5 of the overall effect.

The intuition for this decomposition is the same as in Carvalho et al. (2016). The increase in life expectancy induces households to save more in anticipation of a longer retirement period. This saving-for-retirement motive is stronger for workers, who face a longer expected lifespan, but also affects retirees since their life expectancy continues to increase even after leaving work.[17] The fall in the growth rate

[17]An increase in the retirement age would mitigate this effect. In many OECD countries, pension reforms are moving in this direction. In addition, people work for more years, even though the official retirement age has not changed (Scott, 2021). Yet, Carvalho et al. (2016) show that the increase in retirement age necessary to fully offset the consequences of higher life

Figure 6: Real interest rates in two demographics counterfactuals.



Note: The figure plots the simulated real interest rate from the model for the global economy (blue lines), the young economy (red lines), and the old economy (black lines). The solid lines correspond to the baseline simulation. The dashed-dotted lines are the counterfactual simulations in which the growth rate of the working age population (left) and the probability of surviving (right) remain at their initial values in each country.

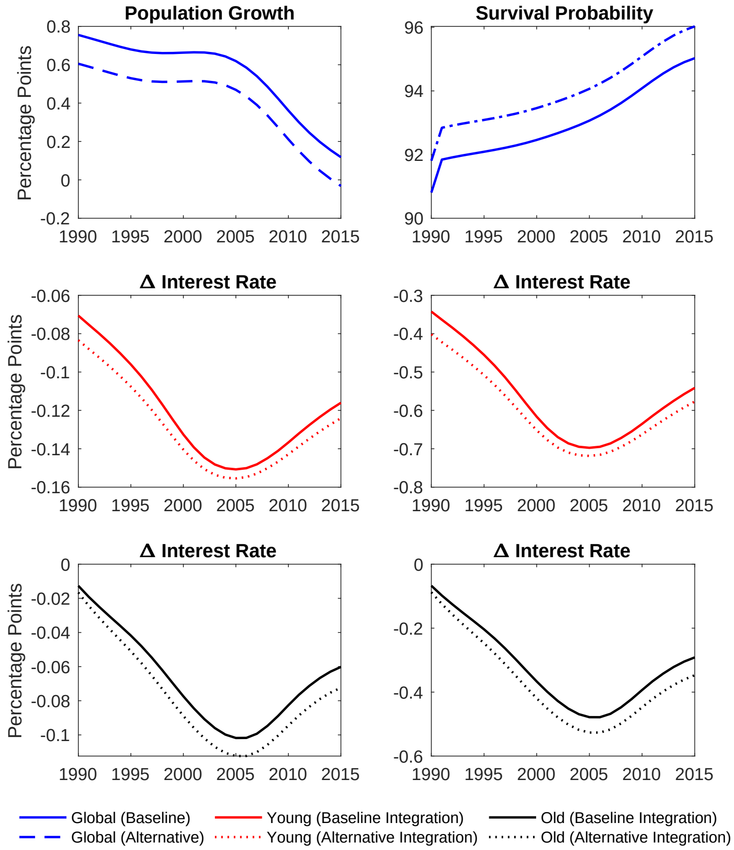
of the working-age population has only a modest effect on the real interest rate because two effects tend to compensate each other. On the one hand, a lower growth rate of the working-age population increases capital per-worker and thus tends to depress returns on financial assets. On the other hand, the reduction in the number of workers implies a change in the composition of the population. Since, retirees have a higher marginal propensity to consume, aggregate savings fall and the real interest rate rises. On balance, the first effect associated with the lower growth rate of the working-age population dominates in the simulation but the quantitative implications are nonetheless small in our model. Overall, the notable consequence of the actual and predicted changes in demographic variables on the real interest rate is due to the increase in life expectancy.

3.3.1 Demographic Comparative Statics

In this section, we perform two comparative-static exercises to understand how global demographic developments affect the real interest rate in the two small economies, and how this effect depends on the degree of financial integration with the rest of the world. We perturb the path of one demographic variable at a time (growth rate of the labor force or probability of surviving) as to generate a parallel upward shift in the dependency ratio relative to the baseline by one percentage point, and assess the impact of the change on the real interest rate of the three regions given different degrees of financial integration.

expectancy on the real interest rate is substantial—well above the changes currently being discussed and implemented in most countries.

Figure 7: Real interest rate sensitivity to alternative demographic profiles.



Note: Change in the real interest rate of the small economy (right) for baseline (solid red line) and high (dotted red line) level of financial integration in response to (i) a more pronounced decline of the growth rate of the labor force in the large economy (dashed blue line, top-left panel); and (ii) a more pronounced increase of the probability of surviving in the large economy (dashed-dotted blue line, bottom-left panel). The solid blue lines in the left column correspond to the baseline processes for demographic variables.

As the top-left panel of Figure 7 shows, we consider a downward shift of the growth rate of the working age population in the global economy by 15 basis points each year (dashed line) relative to the baseline scenario (solid line). The middle-left panel reports the change of the real interest rate relative to the baseline scenario in the young economy. The solid line keeps the degree of financial integration at the same level as in the main simulation. The dotted line corresponds to a higher degree of financial integration (a 25% reduction of the portfolio-holding cost). The downward shift in the trajectory of global population growth leads to a lower real interest rates in the young economy, and this effect is more pronounced the more financially integrated the country is with the global economy. The bottom-left panel plots the same experiment for the old economy. In this case, the consequences of a downward shift of the growth rate of working age population in the global economy for the domestic real interest rate are smaller. The reason is that the old economy is less financially integrated with the global economy than the young economy, and thus is relatively less sensitive to demographic developments in the rest of the world.

Table 4: Real interest rate in 2020 relative to the baseline with different calibrations

Factor	**Baseline**	**Alternative**	$\mathbf{R^{Alt}_{2020} - R^{Base}_{2020}}$
TFP (x)	0.5%	0.6%	15
Debt/GDP (b)	60%	70%	15
Gov't Spending/GDP (g)	25%	26%	16
Pensions/GDP (e)	7.5%	8.5%	36
Age of Retirement (ω)	65	66	50

Note: For each experiment, the first column (Factor) reports the parameter that changes, the second (Baseline) the value in the baseline calibration, the third (Alternative) the value in the alternative calibration, and the fourt ($R^{Alt}_{2020} - R^{Base}_{2020}$) the difference (in basis points) between the real interest rate in 2020 under the alternative calibration relative to the baseline.

The top-right panel of Figure 7 shows an upward shift of the probability of surviving in the global economy by 1 percentage point each year (dashed-dotted line) relative to the baseline scenario (solid line). As in the case of the growth rate of the working age population, the effect of a higher probability of surviving is stronger in the young economy than in the old economy, and is larger with higher financial integration.

Together with the main counteractual analysis of Figure 5, both comparative static exercises in this section reinforce the message that global demographic developments influence the real rate of a small economy progressively more as its financial integration with the rest of the world increases. This point will serve as a guide to interpret the empirical results that we present below.

3.3.2 Other Factors

[**Update this table**]

The existing literature has identified a number of factors that contribute to explain the observed decline of global real interest rates over time. While our analysis focuses on demographic variables, our model is suitable to analyze at least a subset of these other potential drivers. We keep this part deliberately simple and only perform another set of comparative static exercises. Namely, we modify the calibrated value of one factor at a time, this time for the small young economy, and compare the real interest rate so generated with the baseline simulation under the same demographic transition. The last column of Table 4 reports the difference (in basis points) between the real interest rate in the alternative and in the baseline calibration in 2020 for each of these comparative static exercises.

The first line (TFP) reports the consequence of increasing TFP growth (x in the model) from 0.5% as in the baseline calibration to 0.6%. Holston et al. (2017) discuss the importance of the decline in trend GDP growth for the decline of the equilibrium real interest rate. The overall effect in our model, which is consistent with their findings, at least qualitatively, is an increase of the real interest rate by about 15 basis points.

The next three lines (Debt/GDP, Pensions/GDP and Gov't Spending/GDP) correspond to changes in b, e, and g, respectively. In the case of debt, we consider a ten percentage point increase, while for government spending and pensions the change is one percentage point. In all cases, a more expansionary fiscal policy causes a higher interest rate. A 10 percentage point increase in debt/GDP has about the same effect as a one percentage point increase in government spending (15 and 16 basis points, respectively), whereas a one percentage point increase in pensions as a fraction of GDP causes a 36 basis points increase in the real interest rate.

Because of the life-cycle features of the model, government bonds are net wealth for the private sector. Therefore, a higher level of debt relative to GDP supports private sector's consumption and thus contributes to increase the real interest rate. For government spending, the mechanism works through a crowding out of private consumption and investment. The increase in pensions has a large effect on the real interest rate because, effectively, the government transfers resources from agents with lower marginal propensity to consume (workers) to agents with a higher marginal propensity to consume (retirees). Overall, our results about fiscal policy are closely in line with the findings in Rachel and Summers (2019).

The last factor that we consider is the retirement age. In this experiment, we increase the parameter ω so that the average duration of employment is 46 years compared to 45 in the baseline. This exercise approximates the reforms that governments in many countries are implementing to make their public finances, and in particular their pension systems, most sustainable (OECD, 2019). The rise in interest rate in this case is 50 basis points. The intuition is that a longer employment span reduces the incentive for workers to save during their years on the job and thus diminishes the downward pressure on the real interest rate.

Overall, the message from these additional comparative static exercises is that a rebound of TFP growth, a fiscal expansion, or an increase in the retirement age are all factors that could contribute to lift the real interest rate. While the exact magnitudes may depend on the details of the model, we take the direction of the effects as the main lesson to inform our empirical analysis below.

4 Empirical Analysis

The analysis presented in the previous section illustrates how demographic trends may affect real interest rates in a world of imperfect capital mobility. In particular, the model shows that a country's real rate depends on its own demographic developments as well as on global ones. Furthermore, the relative importance of country-specific and global determinants varies with a country's degree of financial integration. The more financially integrated a country is, the higher the sensitivity of its real interest rate to global developments, and the less its own real rate determinants matter. In reverse, the more open an economy is (and the larger its size), the more its fundamentals matter for the equilibrium of the global economy.

We use these implications of the calibrated model as a guide to our empirical analysis of the relationship between demographics and real rates. To that end, we exploit a panel of countries, thus leveraging on variation in these variables across countries and over time. We incorporate lessons from the model by imposing some restrictions in the panel regressions.

Demographic variables exhibit trends that, according to the model, imply low-frequency movements in real interest rates. We take into account the long-run nature of this relationship by employing a panel error-correction model, which allows for cointegrating relationships between real rates and their determinants—demographics in particular.

Among the explanatory variables, we include a measure of the foreign real interest rate faced by each country, interacted with its degree financial openness. This approach allows us to control for determinants of global real rates more broadly, while retaining a parsimonious specification.[18] We then separately add country-specific demographics and other determinants of real rates, interacted with the country's degree of closeness (one minus the degree of openness). Other determinants of real rates include growth in total labor productivity, the retirement age, and other potential determinants highlighted by the literature, as we detail below.

More specifically, our panel error-correction (ECM) model is such that:

$$\begin{aligned}\Delta r_{m,t} = \alpha_m + \gamma r_{m,t-1} + \theta\Theta_{m,t-1}r^*_{m,t-1} + \sum_j \psi_j(1-\Theta_{m,t-1})D_{m,j,t-1} + \sum_k \Psi_k(1-\Theta_{m,t-1})X_{m,k,t-1} \\ + \lambda\Delta(\Theta_{m,t}r^*_{m,t}) + \sum_j \phi_j\Delta[(1-\Theta_{m,t})D_{m,j,t}] + \sum_k \chi_k\Delta[(1-\Theta_{m,t})X_{m,k,t}] + \epsilon_{m,t},\end{aligned}$$

where $r_{m,t}$ is the ex-ante real interest rate of country m and $r^*_{m,t}$ is a global real interest rate faced by country m, whose constructions we detail below. α_m is a country fixed effect, $\Theta_{m,t}$ is a measure of the country's degree of financial openness, $D_{m,\bullet,t}$ stands for a set of demographic variables, and $X_{m,\bullet,t}$ collects control variables and other potential determinants of real rates. Δ is the first-difference operator.

The *ex-ante* short-term real interest rate of country m corresponds to the difference between the time-t short-term nominal rate and the one-period-ahead inflation expectations. To construct the latter, we rely on Hamilton et al. (2015) and set inflation expectations as the one-year-ahead forecast from AR(1) regressions with rolling windows of 20 years. More specifically, the ex-ante real interest rate of country m is $r_{mt} = i_{mt} - \mathbb{E}_t\pi_{mt+1}$, where $\mathbb{E}_t\pi_{mt+1} = \hat{a}_m + \hat{b}_m\pi_{mt}$, and the coefficients $\hat{a}_m$ and $\hat{b}_m$ are the OLS estimates of the regression $\pi_{mt} = a_m + b_m\pi_{mt-1} + \varepsilon_{mt}$ using rolling windows of 20 years.

The global real interest rate that an individual country faces is a weighted average of all other countries' real rates, where the weight associated with each country is the product of its size (in terms of working-age population) and its degree of financial integration. More specifically, we have:

$$r^*_{m,t} = \sum_{\ell\neq m} \frac{POP_{\ell,t}\Theta_{\ell,t}}{\sum_{\ell\neq m} POP_{\ell,t}\Theta_{\ell,t}} r_{\ell,t}.$$

The panel ECM, equation (4), yields estimated long-run relationships between demographic variable j and real rates given by $\hat{\psi}_j/\hat{\gamma}$. In the Appendix B, we entertain an alternative empirical approach to

[18] Alternatively, we could include all determinants of global interest rates as regressors. Because of the relatively small sample, this approach leads to a loss of power.

assess these same relationships.

4.1 Data

We estimate the model in equation (4) using annual data for a set of 19 OECD countries. Our sample covers the period 1980-2019 and includes Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, United Kingdom, and the United States.[19]

We rely on different data sources to construct the variables that enter our regression. Starting with the demographics variables, most series are obtained from the United Nations World Population Prospects. Those series include life expectancy and working-age population. Retirement age is obtained from the OECD database and TFP growth from the Penn World Tables. To map the data to model assumptions, we rely on life expectancy at age 20 and define working-age population as individuals from 20 to 65 years old.

Guided by the model relationships, we convert life expectancy into an "interest-rate-equivalent survival probability." In particular, we first solve for survival probability, $SP_{m,t}$, of country m, such that:

$$LE_{m,t} = RA_{m,t} + \frac{1}{(1 - SP_{m,t})},$$

where $LE_{m,t}$ is life expectancy and $RA_{m,t}$ is the retirement age (both in years) of country m. We then construct the survival probability rate ($SPR_{m,t}$) as:

$$SPR_{m,t} = 100 * (\frac{1}{SP_{m,t}} - 1)$$

We rely on data from Lane and Milesi-Ferretti (2017) to measure financial integration.[20] In particular, we construct an indicator for financial integration, $\Theta_{m,t}$, using the sum of financial assets and liabilities over GDP ($LMF_{m,t}$) such that:

$$\Theta_{m,t} = \frac{LMF_{m,t}}{100 + LMF_{m,t}},$$

where $LMF_{m,t}$ stands for the sum of financial assets and liabilities over GDP (as in Lane and Milesi-Ferretti, 2017). The global real rate that an individual country faces is a weighted average of real rates in all other countries and relies on $\Theta_{m,t}$, as described in equation (4).

The *ex-ante* short-term real interest rate of country m corresponds to the difference between the time-t short-term nominal rate and the one-period-ahead inflation expectations. We obtain data for countries' short-term nominal from various sources as described in Table A1. Inflation rates correspond to headline CPI inflation rates obtained from the OECD.

[19] This sample excludes countries that experienced episodes of high inflation (above 25% in a given year) between 1970 and 2019.

[20] In Appendix we reestimate our regressions while considering trade openness as an alternative proxy for financial integration.

The model introduced in Section 2 isolates the effects of the demographic transition and real interest rates given countries' financial openness. In practice, however, there are other forces at play, as the literature has shown (*e.g.*, Caballero et al., 2017, Holston et al., 2017, Rachel and Smith, 2017, Del Negro et al., 2019, and Mian et al., 2021). Therefore, in our empirical analysis, we assess the effects of demographic variables and the degree of countries' financial openness while also controlling for some of these other forces that are not explicitly specified in our modeling framework. In particular, we control for countries' fiscal stance, which we collect data on government debt and pension spending (both as shares of GDP). The former is obtained from the macroeconomic database of the European Commission (AMECO), while pension spending is obtained from OECD. We also entertain versions in which we control for countries' Gini coefficients, which we obtain from the World Bank, and convenience yields obtained from Del Negro et al. (2019).[21]

4.2 Estimation Results

Table 5 presents our main results from the estimation of equation (4). The table entertains a few alternative specifications. Column (1) considers the effects of demographic variables and TFP growth. Column (2) adds controls for fiscal variables – government debt and pension spending – and the retirement age. Column (3) includes the Gini coefficient as a measure of income inequality. Column (4) adds convenience yields, which, due to data limitations, reduces the sample to 7 countries. Column (5) considers all regressors at once, and for completeness, Column (6) and (7) reestimate the specifications reported in Columns (2) and (3) under the limited sample of 7 countries.

The table shows that, most results align well with the model predictions of Section 2. The survival probability rate has a positive and statistically significant effect on the real rate. Similarly, the growth rate of labor force also has a positive (and statistically significant) effect. Turning to the fiscal variables, the results show that an increase in government debt and an increase in pension spending have a positive impact on the real rate. Moreover, retirement age shows a negative correlation with the real rate. The relationships between real interest rates and inequality and convenience yields, however, are not statistically significant.

The results reported on Table 5, along with the robustness checks reported in Appendix B, give empirical support to the model predictions. The findings highlight the importance of the interaction between demographic variables and financial openness, in addition to considering the effects of other factors to better map the empirical to the theory in the paper.

5 Conclusions

Demographic developments that most advanced economies are undergoing are a natural explanation for the prolonged decline of global real interest rates. We explore the implications of demographic trends

[21] We thank the authors for kindly sharing their series of convenience yields for Canada, France, Germany, Italy, Japan, United Kingdom, and the United States.

Table 5: Estimation results: Panel Error Correction Model

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Global Rate	0.87***	1.08***	1.06***	1.45***	1.52***	1.3***	1.4***
	(0.16)	(0.15)	(0.15)	(0.2)	(0.19)	(0.21)	(0.21)
Survival Rate Probability	0.05	1.74***	1.6***	2.02***	2.16***	2.07***	2.13***
	(0.19)	(0.37)	(0.47)	(0.49)	(0.69)	(0.52)	(0.75)
Growth Rate of Labor Force	3.33***	5.89***	4.89***	8.95***	9.02***	7.19***	7.34***
	(1.17)	(0.98)	(1.17)	(1.47)	(1.73)	(1.44)	(1.84)
TFP Growth	0.71**	0.3	0.07	0.36	0.25	0.36	0.21
	(0.36)	(0.29)	(0.37)	(0.36)	(0.39)	(0.38)	(0.49)
Government Debt		0.05**	0.02	0.09***	0.04	0.07**	0.07*
		(0.02)	(0.03)	(0.03)	(0.05)	(0.03)	(0.04)
Pension Spending		3.24***	2.85***	3.16***	3.27***	3.28***	3.25***
		(0.44)	(0.55)	(0.54)	(0.71)	(0.57)	(0.79)
Retirement Age		-0.64***	-0.54***	-0.79***	-0.91***	-0.76***	-0.78**
		(0.1)	(0.2)	(0.13)	(0.29)	(0.14)	(0.33)
Gini Coefficient			-0.04		0.21		-0.04
			(0.22)		(0.31)		(0.35)
Convenience Yields				-0.89	-2.14		
				(1.28)	(1.95)		
R-Squared	0.24	0.39	0.37	0.57	0.58	0.55	0.55
Adjusted R-Squared	0.21	0.35	0.32	0.51	0.51	0.5	0.48
Observations	743	505	445	206	169	214	175
Clusters	19	19	18	7	7	7	7

Notes: Results from the estimation of equation (4). Robust standard errors, reported in parenthesis, are clustered at the country level. See Section 4 for additional details.

for the evolution of real interest rates over time and across countries. To that end, we first develop a three-country, general-equilibrium model with imperfect capital mobility and differential demographic trends. We use a calibrated three-country version of the model to study how low-frequency movements in a country's real interest rate depend on its own demographics and on global factors, given its degree of financial integration. The more financially integrated a country is, the higher the sensitivity of its real interest rate to global developments, and the less its own real rate determinants matter. Drawing on the lessons from the model, we then estimate panel error-correction models relating real interest rates to possible determinants—including demographics—interacted with measures of countries' degrees of financial integration. The data suggest that financial integration has shifted the dependency of domestic real rates towards global factors, although domestic demographic and fiscal variables still matter somewhat.

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Appendix

A Derivations

This section presents the derivations of the retirees and workers' problems.

A.1 Retirees

Retirees maximize (2) subject to (3). After substituting the constraint into the objective function, we can rewrite the unconstrained maximization problem as

$$V^r_{mt} = \max_{\{A^r_{m\ell t}\}_{\ell=1}^{\mathcal{M}}} \left\{ \left[\frac{1}{\gamma_{mt}} \sum_{\ell=1}^{\mathcal{M}} R_{\ell t-1} A^r_{m\ell t-1} + E^r_{mt} - \left(1 + \sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t} \left(\eta^r_{m\ell t} - \bar{\eta}_{nm} \right)^2}{2} \right) \sum_{\ell=1}^{\mathcal{M}} A^r_{m\ell t} \right]^{\frac{\sigma-1}{\sigma}} \right.$$
$$\left. + \gamma_{mt+1} \beta_m (V^r_{mt+1})^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}}.$$

The first-order condition with respect to foreign assets (A^r_{mpt}, $p \neq m$) is

$$\left[\left(1 + \sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2} \left(\eta^r_{m\ell t} - \bar{\eta}_{m\ell} \right)^2 \right) - \sum_{\ell=1}^{\mathcal{M}} \Lambda_{m\ell t} \left(\eta^r_{m\ell t} - \bar{\eta}_{m\ell} \right) \eta^r_{m\ell t} + \Lambda_{mpt} \left(\eta^r_{mpt} - \bar{\eta}_{mp} \right) \left(1 - \eta^r_{mpt} \right) \right] (C^r_{mt})^{-\frac{1}{\sigma}}$$
$$= \beta_m \gamma_{mt+1} \left(V^r_{mt+1} \right)^{-\frac{1}{\sigma}} \frac{\partial V^r_{mt+1}}{\partial A^r_{mpt}},$$

while the first-order condition with respect to domestic assets (A^r_{mmt}) is

$$\left[\left(1 + \sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2} \left(\eta^r_{m\ell t} - \bar{\eta}_{m\ell} \right)^2 \right) - \sum_{\ell=1}^{\mathcal{M}} \Lambda_{m\ell t} \left(\eta^r_{m\ell t} - \bar{\eta}_{m\ell} \right) \eta^r_{m\ell t} \right] (C^r_{mt})^{-\frac{1}{\sigma}}$$
$$= \beta_m \gamma_{mt+1} \left(V^r_{mt+1} \right)^{-\frac{1}{\sigma}} \frac{\partial V^r_{mt+1}}{\partial A^r_{mmt}}.$$

By the Envelope Theorem, the partial derivatives above are

$$\frac{\partial V^r_{mt+1}}{\partial A^r_{mpt}} = \left(V^r_{mt+1} \right)^{\frac{1}{\sigma}} \left(C^r_{mt+1} \right)^{-\frac{1}{\sigma}} \frac{R_{pt}}{\gamma_{mt+1}}, \quad \forall\, p = 1, ..., \mathcal{M}. \tag{A.1}$$

Substituting (A.1) into the first-order conditions above gives

$$\left[\left(1 + \sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2} \left(\eta^r_{m\ell t} - \bar{\eta}_{m\ell} \right)^2 \right) - \sum_{\ell=1}^{\mathcal{M}} \Lambda_{m\ell t} \left(\eta^r_{m\ell t} - \bar{\eta}_{m\ell} \right) \eta^r_{m\ell t} + \Lambda_{mpt} \left(\eta^r_{mpt} - \bar{\eta}_{mp} \right) \left(1 - \eta^r_{mpt} \right) \right] (C^r_{mt})^{-\frac{1}{\sigma}}$$
$$= \beta_m R_{pt} (C^r_{mt+1})^{-\frac{1}{\sigma}}, \tag{A.2}$$

and

$$\left[\left(1+\sum_{\ell=1}^{\mathcal{M}}\frac{\Lambda_{m\ell t}}{2}\left(\eta^r_{m\ell t}-\bar{\eta}_{m\ell}\right)^2\right)-\sum_{\ell=1}^{\mathcal{M}}\Lambda_{m\ell t}\left(\eta^r_{m\ell t}-\bar{\eta}_{m\ell}\right)\eta^r_{m\ell t}\right](C^r_{mt})^{-\frac{1}{\sigma}}=\beta_m R_{mt}(C^r_{mt+1})^{-\frac{1}{\sigma}}. \tag{A.3}$$

Dividing (A.2) by (A.3) and rearranging yields:

$$\left[1+\sum_{\ell=1}^{\mathcal{M}}\frac{\Lambda_{m\ell t}}{2}\left(\eta^r_{m\ell t}-\bar{\eta}_{m\ell}\right)^2\right](R_{pt}-R_{mt})=\Lambda_{mp}\left(\eta^r_{mpt}-\bar{\eta}_{mp}\right)R_{mt},$$

which correspond to equation (4) in the main text.

Next, if we multiply equation (A.2) by η^r_{mmt} and equation (A.3) by $\sum_{\ell=1}^{\mathcal{M}}\eta_{m\ell t}\eta^r_{m\ell t}$, and we add them up, we obtain the Euler equation for the optimal path of consumption of retirees

$$C^r_{mt+1}=\left[\frac{\beta_m\sum_{\ell=1}^{n}\eta^r_{m\ell t}R_{\ell t}}{1+\sum_{\ell=1}^{\mathcal{M}}\frac{\Lambda_{m\ell t}}{2}\left(\eta^r_{m\ell t}-\bar{\eta}_{m\ell}\right)^2}\right]^{\sigma}C^r_{mt}. \tag{A.4}$$

In order to find the difference equation for the marginal propensity to consume out of wealth for retirees, we substitute the retirees budget constraint (3) into the policy function (5). After rearranging, we obtain

$$\frac{1-\xi^r_{mt}}{\xi^r_{mt}}C^r_{mt}=\left[1+\sum_{\ell=1}^{\mathcal{M}}\frac{\Lambda_{m\ell t}}{2}\left(\eta^r_{m\ell t}-\bar{\eta}_{m\ell}\right)^2\right]\sum_{\ell=1}^{\mathcal{M}}A^r_{m\ell t}+\frac{\gamma_{mt+1}S^r_{mt+1}}{\tilde{R}_{mt}},$$

where the present discounted value of pension benefits to retirees S^r_{mt} and the adjusted return $\tilde{R}_{mt}$ are defined in the text. Replacing for current consumption from the Euler equation (A.4) , we obtain

$$\frac{1-\xi^r_{mt}}{\xi^r_{mt}}C^r_{mt+1}(\beta_m\tilde{R}_{mt})^{-\sigma}=\left[1+\sum_{\ell=1}^{\mathcal{M}}\frac{\Lambda_{m\ell t}}{2}\left(\eta^r_{m\ell t}-\bar{\eta}_{m\ell}\right)^2\right]\sum_{\ell=1}^{\mathcal{M}}A^r_{m\ell t}+\frac{\gamma_{mt+1}S^r_{mt+1}}{\tilde{R}_{mt}}$$

Finally, we can substitute the guess of the consumption function at $t+1$ for C^r_{mt+1} to obtain

$$\begin{aligned}\frac{1-\xi^r_{mt}}{\xi^r_{mt}}\xi^r_{mt+1}&\left(\frac{1}{\gamma_{mt+1}}\sum_{\ell=1}^{\mathcal{M}}R_{\ell t}A^r_{m\ell t}+S^r_{mt+1}\right)(\beta_m\tilde{R}_{mt})^{-\sigma}\\&=\left[1+\sum_{\ell=1}^{\mathcal{M}}\frac{\Lambda_{m\ell t}}{2}\left(\eta^r_{m\ell t}-\bar{\eta}_{m\ell}\right)^2\right]\sum_{\ell=1}^{\mathcal{M}}A^r_{m\ell t}+\frac{\gamma_{mt+1}S^r_{mt+1}}{\tilde{R}_{mt}}\end{aligned}$$

Dividing by $\sum_{\ell=1}^{\mathcal{M}}A^r_{m\ell t}$ and using the definition of η_{mpt} allows us to obtain (7) in the text.

Finally, we guess and verify that the value function is linear in the level of consumption:

$$V^r_{mt}=\Delta^r_{mt}C^r_{mt}.$$

Substituting the guess into the functional equation (2) together with the Euler equation (A.4) to eliminate

C^r_{mt+1}, we obtain

$$\Delta^r_{mt} C^r_{mt} = \left[(C^r_{mt})^{\frac{\sigma-1}{\sigma}} + \beta_m \gamma_{mt+1} \left(\Delta^r_{mt+1}\right)^{\frac{\sigma-1}{\sigma}} (\beta_m \tilde{R}_{mt})^{\sigma-1} (C^r_{mt})^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}.$$

We can simplify the last expression by eliminating the terms in C^r_{mt}. After rearranging, we obtain

$$\frac{1}{(\Delta^r_{mt})^{\frac{\sigma-1}{\sigma}}} = 1 - \gamma_{mt+1} \beta^\sigma_m \tilde{R}^{\sigma-1}_{mt} \left(\frac{\Delta^r_{mt+1}}{\Delta^r_{mt}} \right)^{\frac{\sigma-1}{\sigma}}. \tag{A.5}$$

Comparing (A.5) with the difference equation for the marginal propensity to consume (7), we can see that

$$\Delta^r_{mt} = (\xi^r_{mt})^{-\frac{\sigma}{\sigma-1}}.$$

A.2 Workers

The workers' problem is to maximize (8) subject to (9). After substituting the constraint into the objective, the unconstrained maximization problem becomes

$$V^w_{mt} = \max_{\{A^w_{m\ell t}\}^{\mathcal{M}}_{\ell=1}} \left\{ \left[\sum_{\ell=1}^{\mathcal{M}} R_{\ell t-1} A^w_{m\ell t-1} + W^w_{mt} - T^w_{mt} - \left(1 + \sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2} \left(\eta^w_{m\ell t} - \bar{\eta}_{nm}\right)^2 \right) \sum_{\ell=1}^{\mathcal{M}} A^w_{m\ell t} \right]^{\frac{\sigma-1}{\sigma}} \right.$$
$$\left. + \beta_m \left[\omega_{mt+1} V^w_{mt+1} + (1-\omega_{mt+1}) V^{rt+1}_{mt+1} \right]^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}}.$$

The first-order condition with respect to country-p assets (with $p \neq m$) is

$$\left[\left(1 + \sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2} \left(\eta^w_{m\ell t} - \bar{\eta}_{m\ell}\right)^2 \right) - \sum_{\ell=1}^{\mathcal{M}} \Lambda_{m\ell t} \left(\eta^w_{m\ell t} - \bar{\eta}_{m\ell}\right) \eta^w_{m\ell t} + \Lambda_{mpt} \left(\eta^w_{mpt} - \bar{\eta}_{mp}\right) \left(1 - \eta^w_{mpt}\right) \right] (C^w_{mt})^{-\frac{1}{\sigma}}$$
$$= \beta_m \left[\omega_{mt+1} V^w_{mt+1} + (1-\omega_{mt+1}) V^r_{mt+1} \right]^{-\frac{1}{\sigma}} \left[\omega_{mt+1} \frac{\partial V^w_{mt+1}}{\partial A^w_{mpt}} + (1-\omega_{mt+1}) \frac{\partial V^r_{mt+1}}{\partial A^r_{mpt}} \right], \tag{A.6}$$

while the first-order condition with respect to domestic assets is

$$\left[\left(1 + \sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2} \left(\eta^w_{m\ell t} - \bar{\eta}_{m\ell}\right)^2 \right) - \sum_{\ell=1}^{\mathcal{M}} \Lambda_{m\ell t} \left(\eta^w_{m\ell t} - \bar{\eta}_{m\ell}\right) \eta^w_{m\ell t} \right] (C^w_{mt})^{-\frac{1}{\sigma}}$$
$$= \beta_m \left[\omega_{mt+1} V^w_{mt+1} + (1-\omega_{mt+1}) V^r_{mt+1} \right]^{-\frac{1}{\sigma}} \left[\omega_{mt+1} \frac{\partial V^w_{mt+1}}{\partial A^w_{mmt}} + (1-\omega_{mt+1}) \frac{\partial V^r_{mt+1}}{\partial A^r_{mmt}} \right]. \tag{A.7}$$

As for retirees, we use the Envelope Theorem to calculate the partial derivatives above

$$\frac{\partial V^w_{mt+1}}{\partial A^w_{mpt}} = \left(V^w_{mt+1}\right)^{\frac{1}{\sigma}} \left(C^w_{mt+1}\right)^{-\frac{1}{\sigma}} R_{pt}. \tag{A.8}$$

To solve the workers' problem, we need to guess the functional form of the value function at this stage. Like for retirees, we conjecture that the value function is linear in consumption and the slope is the same function of the marginal propensity to consume

$$V_{mt}^{w} = \Delta_{mt}^{w} C_{mt}^{w}, \quad \text{with} \quad \Delta_{mt}^{w} = \left(\xi_{mt}^{w}\right)^{-\frac{\sigma}{\sigma-1}}. \tag{A.9}$$

By substituting equation (A.8) and the guess (A.9) into equation (A.7) we get

$$\begin{aligned}
&\left[\left(1+\sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2}\left(\eta_{m\ell t}^{w}-\bar{\eta}_{m\ell}\right)^{2}\right)-\sum_{\ell=1}^{\mathcal{M}} \Lambda_{m\ell t}\left(\eta_{m\ell t}^{w}-\bar{\eta}_{m\ell}\right) \eta_{m\ell t}^{w}\right]\left(C_{mt}^{w}\right)^{-\frac{1}{\sigma}} \\
&=\beta_{m}\left[\omega_{mt+1} \Delta_{mt+1}^{w} C_{mt+1}^{w}+(1-\omega_{mt+1}) \Delta_{mt+1}^{r} C_{mt+1}^{r}\right]^{-\frac{1}{\sigma}}\left[\omega_{mt+1}\left(\Delta_{mt+1}^{w}\right)^{\frac{1}{\sigma}}+(1-\omega_{mt+1})\left(\Delta_{mt+1}^{r}\right)^{\frac{1}{\sigma}}\right].
\end{aligned} \tag{A.10}$$

Multiplying both sides of (A.10) by $(\Delta_{mt+1}^{w})^{\frac{1}{\sigma}}$ and rearranging yields

$$\begin{aligned}
&\left[\omega_{mt+1} C_{mt+1}^{w}+(1-\omega_{mt+1}) \frac{\Delta_{mt+1}^{r}}{\Delta_{mt+1}^{w}} C_{mt+1}^{r}\right]^{\frac{1}{\sigma}} \\
&\qquad=\frac{\beta_{m}\left[\omega_{mt+1}+(1-\omega_{mt+1})\left(\frac{\Delta_{mt+1}^{r}}{\Delta_{mt+1}^{w}}\right)^{\frac{1}{\sigma}}\right] R_{mt}\left(C_{mt}^{r}\right)^{\frac{1}{\sigma}}}{\left[1+\sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2}\left(\eta_{m\ell t}^{w}-\bar{\eta}_{m\ell}\right)^{2}\right]-\sum_{\ell=1}^{\mathcal{M}} \Lambda_{m\ell t}\left(\eta_{m\ell t}^{w}-\bar{\eta}_{m\ell}\right) \eta_{m\ell t}^{w}}.
\end{aligned}$$

Using the solution for the value function of retirees and the guess for the value function of workers, we can rewirte the last expression as

$$\begin{aligned}
&\left[\omega_{mt+1} C_{mt+1}^{w}+(1-\omega_{mt+1})\left(\frac{\xi_{mt+1}^{r}}{\xi_{mt+1}^{w}}\right)^{\frac{\sigma}{1-\sigma}} C_{mt+1}^{r}\right]^{\frac{1}{\sigma}} \\
&\qquad=\frac{\beta_{m}\left[\omega_{mt+1}+(1-\omega_{mt+1})\left(\frac{\xi_{mt+1}^{r}}{\xi_{mt+1}^{w}}\right)^{\frac{1}{1-\sigma}}\right] R_{mt}\left(C_{mt}^{r}\right)^{\frac{1}{\sigma}}}{\left[1+\sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2}\left(\eta_{m\ell t}^{w}-\bar{\eta}_{m\ell}\right)^{2}\right]-\sum_{\ell=1}^{\mathcal{M}} \Lambda_{m\ell t}\left(\eta_{m\ell t}^{w}-\bar{\eta}_{m\ell}\right) \eta_{m\ell t}^{w}}.
\end{aligned} \tag{A.11}$$

Following the same steps for equation (A.6), we obtain

$$\begin{aligned}
&\left[\omega_{mt+1} C_{mt+1}^{w}+(1-\omega_{mt+1})\left(\frac{\xi_{mt+1}^{r}}{\xi_{mt+1}^{w}}\right)^{\frac{\sigma}{1-\sigma}} C_{mt+1}^{r}\right]^{\frac{1}{\sigma}}= \\
&\frac{\beta_{m}\left[\omega_{mt+1}+(1-\omega_{mt+1})\left(\frac{\xi_{mt+1}^{r}}{\xi_{mt+1}^{w}}\right)^{\frac{1}{1-\sigma}}\right] R_{pt}\left(C_{mt}^{r}\right)^{\frac{1}{\sigma}}}{\left[1+\sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2}\left(\eta_{m\ell t}^{w}-\bar{\eta}_{m\ell}\right)^{2}\right]-\sum_{\ell=1}^{\mathcal{M}} \Lambda_{m\ell t}\left(\eta_{m\ell t}^{w}-\bar{\eta}_{m\ell}\right) \eta_{m\ell t}^{w}+\Lambda_{mpt}(\eta_{mpt}^{w}-\bar{\eta}_{mp})}.
\end{aligned} \tag{A.12}$$

Dividing equation (A.11) by equation (A.12) shows that workers choose asset shares according to the same condition as retirees

$$\left[1+\sum_{\ell=1}^{\mathcal{M}}\frac{\Lambda_{m\ell t}}{2}\left(\eta_{m\ell t}^{w}-\bar{\eta}_{m\ell}\right)^{2}\right]\left(R_{pt}-R_{mt}\right)=\Lambda_{mpt}\left(\eta_{mpt}^{w}-\bar{\eta}_{mp}\right)R_{mt},$$

which implies $\eta_{mpt}^{w}=\eta_{mpt}^{r}=\eta_{mpt}\ \forall p$.

We can find the Euler equation for workers' consumption following the same steps we did for retirees and get

$$\omega_{mt+1}C_{mt+1}^{w}+(1-\omega_{mt+1})\left(\frac{\xi_{mt+1}^{r}}{\xi_{mt+1}^{w}}\right)^{\frac{\sigma}{1-\sigma}}C_{mt+1}^{r}=\left(\beta_{m}\Omega_{mt+1}\tilde{R}_{mt}\right)^{\sigma}C_{mt}^{r}, \tag{A.13}$$

with Ω_{mt} defined in (11) in the text.

Next, we substitute the guesses for the policy functions, (5) and (10), for C_{mt+1}^{r} and C_{mt+1}^{w}, respectively, in (A.13) to obtain

$$\omega_{mt+1}\xi_{mt+1}^{w}\left(\sum_{\ell=1}^{\mathcal{M}}R_{\ell t}A_{m\ell t}^{w}+H_{mt+1}^{w}+Z_{mt+1}^{w}\right)+(1-\omega_{mt+1})\left(\frac{\xi_{mt+1}^{r}}{\xi_{mt+1}^{w}}\right)^{\frac{1}{1-\sigma}}\xi_{mt+1}^{w}\left(\sum_{\ell=1}^{\mathcal{M}}R_{\ell t}A_{m\ell t}^{r}+S_{mt+1}^{r}\right)$$
$$=\left(\beta_{m}\Omega_{mt+1}\tilde{R}_{mt}\right)^{\sigma}\xi_{mt}^{w}\left(\sum_{\ell=1}^{\mathcal{M}}R_{\ell t-1}A_{m\ell t-1}^{w}+H_{mt}^{w}+Z_{mt}^{w}\right).$$

Dividing this expression by ξ_{mt+1}^{w} and $\sum_{\ell=1}^{\mathcal{M}}\eta_{m\ell t}R_{\ell t}$ gives us

$$\omega_{mt+1}\left(\sum_{\ell=1}^{\mathcal{M}}A_{m\ell t}^{w}+\frac{H_{mt+1}^{w}+Z_{mt+1}^{w}}{\sum_{\ell=1}^{\mathcal{M}}\eta_{m\ell t}R_{\ell t}}\right)+(1-\omega_{mt+1})\left(\frac{\xi_{mt+1}^{r}}{\xi_{mt+1}^{w}}\right)^{\frac{1}{1-\sigma}}\left(\sum_{\ell=1}^{\mathcal{M}}A_{m\ell t}^{r}+\frac{S_{mt+1}^{r}}{\sum_{\ell=1}^{\mathcal{M}}\eta_{m\ell t}R_{\ell t}}\right)$$
$$=\left[\frac{\beta_{m}\Omega_{mt+1}}{1+\sum_{\ell=1}^{\mathcal{M}}\frac{\Lambda_{m\ell t}}{2}\left(\eta_{m\ell t}^{w}-\bar{\eta}_{m\ell}\right)^{2}}\right]^{\sigma}\left(\sum_{\ell=1}^{\mathcal{M}}\eta_{m\ell t}R_{\ell t}\right)^{\sigma-1}\frac{\xi_{mt}^{w}}{\xi_{mt+1}^{w}}\left(\sum_{\ell=1}^{\mathcal{M}}R_{\ell t-1}A_{m\ell t-1}^{w}+H_{mt}^{w}+Z_{mt}^{w}\right).$$

Note that, for a worker who retires, $\sum_{\ell=1}^{\mathcal{M}}A_{m\ell t}^{w}=\sum_{\ell=1}^{\mathcal{M}}A_{m\ell t}^{r}$. Therefore, we can simplify the previous equation using the workers' budget constraint as to obtain

$$\sum_{\ell=1}^{\mathcal{M}}R_{\ell t-1}A_{m\ell t-1}^{w}+W_{mt}^{w}+T_{mt}^{w}-C_{mt}^{w}+\frac{\omega_{mt+1}(H_{mt+1}^{w}+Z_{mt+1}^{w})}{\Omega_{mt+1}\tilde{R}_{mt}}+\frac{(1-\omega_{mt+1})\left(\frac{\xi_{mt+1}^{r}}{\xi_{mt+1}^{w}}\right)^{\frac{1}{1-\sigma}}S_{mt+1}^{r}}{\Omega_{mt+1}\tilde{R}_{mt}}$$
$$=\beta_{m}^{\sigma}\left(\Omega_{mt+1}\tilde{R}_{mt}\right)^{\sigma-1}\frac{\xi_{mt}^{w}}{\xi_{mt+1}^{w}}\left(\sum_{\ell=1}^{\mathcal{M}}R_{\ell t-1}A_{m\ell t-1}^{w}+H_{mt}^{w}+Z_{mt}^{w}\right).$$

Substituting the guess for C_{mt}^{w} and using the recursive definitions of H_{mt+1}^{w} and Z_{mt+1}^{w}, we get the difference equation for the marginal propensity to consume of workers (12)

The last step to characterize the workers' problem is to verify the guess for the value function. After substituting the guess into equation (8) and rearranging, we get

$$\Delta^w_{mt}C^w_{mt} = \left\{ \left(C^w_{mt}\right)^{\frac{\sigma-1}{\sigma}} + \beta_m \left[\omega_{mt+1}C^w_{mt+1} + (1-\omega_m t+1)\frac{\Delta^r_{mt+1}}{\Delta^w_{mt+1}}C^r_{mt+1} \right]^{\frac{\sigma-1}{\sigma}} \left(\Delta^w_{mt+1}\right)^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}}. \quad \text{(A.14)}$$

We can then substitute the Euler equation (A.13) into (A.14) and write

$$\Delta^w_{mt}C^w_{mt} = \left\{ \left(C^w_{mt}\right)^{\frac{\sigma-1}{\sigma}} + \beta_m \left[(\beta_m \Omega_{mt+1}\tilde{R}_{mt})^{\sigma} C^w_{mt} \right]^{\frac{\sigma-1}{\sigma}} \left(\Delta^w_{mt+1}\right)^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}}.$$

Simplifying C^w_{mt} from the equation and rearranging leads to

$$\left(\Delta^w_{mt}\right)^{\frac{\sigma-1}{\sigma}} = 1 + \beta^{\sigma}_m \left(\Omega_{mt+1}\tilde{R}_{mt}\right)^{\sigma-1} \left(\Delta^w_{mt+1}\right)^{\frac{\sigma-1}{\sigma}}. \quad \text{(A.15)}$$

Comparing equation (A.15) to equation (12) shows that the guess for the policy function is correct provided that

$$\Delta^w_{mt} = \left(\xi^w_{mt}\right)^{-\frac{\sigma}{\sigma-1}}.$$

A.3 Assets

The heterogeneity between workers and retirees makes it necessary to keep track of the distribution of wealth between the two groups. We start by writing the law of motion of the amount of assets held by retirees

$$\sum_{\ell=1}^{\mathcal{M}} A^r_{m\ell t} = \frac{\sum_{\ell=1}^{\mathcal{M}} R_{\ell t-1}A^r_{m\ell t-1} + E_{mt} - C^r_{mt}}{1 + \sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2}\left(\eta_{m\ell t} - \bar{\eta}_{m\ell}\right)^2} + (1-\omega_{mt+1})\frac{\sum_{\ell=1}^{\mathcal{M}} R_{\ell t-1}A^w_{m\ell t-1} + W_{mt} - T_{mt} - C^w_{mt}}{1 + \sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2}\left(\eta_{m\ell t} - \bar{\eta}_{m\ell}\right)^2}. \quad \text{(A.16)}$$

From the workers' aggregate budget constraint, we substitute the total amount of workers' assets into the second term of the right-hand side of equation (A.16). Next, we substitute out retirees' consumption, and rewrite retirees and workers' total value of non-human assets as shares of total assets using the definition in the text

$$\lambda_{mt}\sum_{\ell=1}^{\mathcal{M}} A_{m\ell t} - \frac{1-\omega_{mt+1}}{\omega_{mt+1}}(1-\lambda_{mt})\sum_{\ell=1}^{\mathcal{M}} A_{m\ell t}$$
$$= \frac{\lambda_{mt-1}\sum_{\ell=1}^{\mathcal{M}} R_{\ell t-1}A_{m\ell t-1} + E_{mt} - \xi^r_{mt}\left(\lambda_{mt-1}\sum_{\ell=1}^{\mathcal{M}} R_{\ell t-1}A_{m\ell t-1} + S_{mt}\right)}{1 + \sum_{\ell=1}^{\mathcal{M}} \frac{\Lambda_{m\ell t}}{2}\left(\eta_{m\ell t} - \bar{\eta}_{m\ell}\right)^2}.$$

After rearranging and using the definition of aggregate assets $A_{mt} \equiv \sum_{\ell=1}^{\mathcal{M}} A_{m\ell t}$, we obtain equation (14) in the text.

B Empirical analysis

B.1 Data

Table A1: Sources for nominal short-term interest rates used to construct *ex-ante* real interest rates

Country	Source	Description
Australia	World Bank	Lending interest rate
Austria	OECD	1D central bank yield
Belgium	OECD	3M interbank yield
Canada	OECD	1D central bank yield
Denmark	OECD	1D central bank yield
Finland	OECD	1D central bank yield
France	OECD	3M interbank rate
Germany	AMECO	Short term interest rate
Ireland	OECD	3M interbank rate
Italy	AMECO	Short term interest rate
Japan	OECD	1D central bank yield
Netherlands	AMECO	Short term interest rate
New Zealand	OECD	3M bankbill yield
Norway	OECD	3M interbank yield
Spain	OECD	3M interbank rate
Sweden	OECD	3M interbank rate
Switzerland	OECD	3M interbank loan rate
United Kingdom	OECD	3M interbank loan rate
United States	IFS	Money market rate

B.2 Alternative empirical approach

As a robustness exercise, we also consider an alternative empirical specification in which we account for common trends and long-term empirical relationships by estimating our panel regressions as deviations from cross-country averages. More specifically, for each variable $Y_{m,t}$ included in our estimates, we subtract it from its global equivalent, $Y^*_{m,t}$, where the latter is a weighted average of the corresponding variable for all other countries:

$$Y^*_{m,j,t} = \sum_{\ell \neq m} \frac{POP_{\ell,t}\Theta_{\ell,t}}{\sum_{\ell \neq m} POP_{\ell,t}\Theta_{\ell,t}} Y_{\ell,j,t}.$$

We rely on these constructed variables to estimate:

$$r_{m,t} - r^*_{m,t} = \alpha_m + (1 - \Theta_{m,t}) \left(\sum_j \psi_j (D_{m,j,t} - D^*_{m,j,t}) + \sum_k \Psi_k (X_{m,k,t} - X^*_{m,k,t}) \right) + \epsilon_{m,t},$$

where $r_{m,t}$ is the real interest rate of country m at time t, $r^*_{m,t}$ is the global real interest rate calculated as described in equation (B.2). $D_{m,t}$ and $X_{m,k,t}$ are country-m demographics and control variables, respectively, and $D^*_{m,t}$ and $X^*_{m,k,t}$ are global demographic and other control variables faced by country m, constructed as described in equation (B.2).

Table A2 reports our main findings. It shows results for the same specifications reported for the panel

ECM of Table 5. Note that because the dependent variable is substracted from the global rate, the latter does not enter as a regressor in this empirical setting.

Table A2: Estimation results – Demeaned estimates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Survival Rate Probability	-0.46***	1.46***	1.83***	2.35***	5.53***	1.46***	1.83***
	(0.11)	(0.29)	(0.68)	(0.44)	(1.08)	(0.29)	0.68
Growth Rate of Labor Force	-0.08	4.49***	4.29***	5.08***	5.39***	4.49***	4.29***
	(0.48)	(0.57)	(0.72)	(0.9)	(1.18)	(0.57)	0.72
TFP Growth	0.07	0.11	-0.04	0.2	-0.15	0.11	-0.04
	(0.13)	(0.13)	(0.15)	(0.18)	(0.2)	(0.13)	0.15
Government Debt		0.03***	-0.04***	0.03**	-0.07***	0.03***	-0.04***
		(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	0.01
Pension Spending		1.86***	1.47***	2.86***	3.2***	1.86***	1.47***
		(0.19)	(0.22)	(0.38)	(0.52)	(0.19)	0.22
Retirement Age		-1.25***	-1.3**	-0.75*	-1.93**	-1.25***	-1.3**
		(0.26)	(0.54)	(0.41)	(0.89)	(0.26)	0.54
Gini Coefficient			0.18***		0.24***		0.18***
			(0.04)		(0.07)		0.04
Convenience Yields				-4.38***	-9.42***		
				(1.33)	(1.62)		
R-Squared	0.04	0.2	0.07	0.39	0.29	0.35	0.19
Adjusted R-Squared	0.01	0.16	0.02	0.35	0.23	0.31	0.13
Observations	763	526	465	213	176	221	182
Clusters	19	19	18	7	7	7	7

Notes: Results from the estimation of equation (B.2). All results are based on clustered (at the country level) robust standard errors. See Section 4 for additional details.