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ABSTRACT

Since the early 1990's the growth rates of the four largest European economies—France, Germany, Italy, and the United Kingdom—have slowed. This persistent slowdown suggests a low-frequency structural change is at work. A combination of longer individual life expectancies and declining fertility have led to gradually ageing populations. Demographic change affects economic growth directly through households savings and labor supply decisions and also growth indirectly through the pension systems and the need to fund them. Tax increases to balance budgets will impose additional distortions to individual factor-supply choices. We quantify the growth effects from aging and from the financing of public pensions, and we estimate the welfare gains from pension reforms.

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1 Introduction

One of the most striking characteristics of advanced economies has been the secular rise in life expectancy. During the last 50 years, life expectancy at birth in advanced economies has increased by over ten years and, according to U.N projections, it is expected to continue increasing.[1] This impressive increase in longevity combined with a decrease in fertility has resulted in aging populations in most of the developed economies. Despite longer, and presumably healthier lives, life-cycle labor-supply choices, particularly retirement behavior, have changed less.

Ageing populations have powerful implications. At the individual level, increases in life expectancy affect consumption, labor supply and savings decisions as households must adapt to a longer life span and changes in factor prices. Many prior studies of the impact of demographic change have only focused on savings choices and not considered how demographic change also affects labor-supply choices.[2] Here we show that labor supply decisions are the biggest contributing factor to growth.

We use a parsimonious model to better understand the behavioral responses to increases in life expectancy and changing factor prices. A structural approach is needed to (i) make projections for future growth, (ii) analyze policy responses to stagnating economic growth, and (iii) have a laboratory to evaluate the welfare consequences of policy alternatives. Often proposals to reform pension systems, for example extending the eligibility age, are evaluated simply on the basis of their impact on cost and output. But, a structural model is essential to evaluate the welfare consequences of those reforms because increasing labor force participation at older ages has some associated utility costs that come from the labor leisure trade-off.

We study the impact of changing demographics for aggregate growth in Europe's four largest economies: France, Germany, Italy, and the United Kingdom. Since the early 1990's these four economies have experienced a slowdown in long-run growth that is persistent but not uniform. Compared to the prior two decades, annualized long run growth over the last 20 years fell by

[1] Case and Deaton (2017) have documented a recent slight decrease in life expectancy among U.S. males in certain socioeconomic groups due to "Deaths of Despair" – deaths due to suicide, drug overdose and obesity. This is largely a U.S. phenomenon not in evidence in other countries.

[2] Krueger and Ludwig (2007), Backus, Cooley, and Henriksen (2014), and Ferrero (2010) investigate the effect of demographic change on real interest rates and international capital flows, assuming that individuals supply labor inelastically between fixed ages. See also Henriksen and Lambert (2018), Feroli (2003), Sposi (2019), and Bárány, Coeurdacier, and Guibaud (2019) Similarly, also using models solely focusing on savings decisions, Gagnon, Johannsen, and López-Salido (2016), Carvalho, Ferrero, and Nechio (2016), and Ikeda and Saito (2014) show the impact of demographic factors on the real interest rate in the United States and Japan. We separately show that both the quantitative and qualitative implications of aging populations hinge crucially on how individual labor supply responds to increases in life expectancy.

between 0.8 percentage points in the United Kingdom and 2.2 percentage points in Italy. At the same time, these countries have experienced persistent increases in longevity and declines in fertility rates. The combination of these two factors has resulted in populations aging to different degrees within each country. In this paper, we quantify the impact of demographic change on aggregate factor supply and demand, and on the growth experience of these economies, including the indirect growth effects of the additional frictions and distortions that result from higher marginal taxes necessary to finance the pension benefits of an ageing society.[3]

Traditional growth accounting allocates growth outcomes to total factor productivity growth, population growth, and changes in factor supplies–specifically capital accumulation and labor supply on both the intensive and extensive margin. Changes in the life expectancy and the age-cohort distribution of countries affect all of these channels. An increase in longevity affects individual factor supply decisions whereas changes in the age composition of populations affects the aggregation of individual assets and labor supply. Changes in the aggregation of labor supply also affects measured TFP as a greater or smaller fraction of those choosing to work may be in the most productive years of their lives as the relative cohort distribution changes. The combination of these forces induces general equilibrium effects, with changes in factor prices further affecting individual decisions.

Demographic change also affects the aforementioned growth channels indirectly through pension systems. As populations age, and individuals either choose or are forced into retirement, governments' pension liabilities increase. Coupled with a shrinking tax base as the relative number of individuals choosing to work decreases, tax rates must adjust to balance government budgets. Increases in tax rates introduce additional frictions and distortions to individual saving and labor supply decisions, providing further headwinds for economic growth.

Using a general equilibrium overlapping generations model with a rich demographic structure, endogenous retirement, age heterogeneity in productivity, and a pay-as-you-go pension system, we find that the contribution of demographic change to growth is substantial and can account for as much as 70% of the secular growth slowdown in the case of France and Germany. For the United Kingdom and Italy, demographic change can account for 50% and 25% of their respective growth slowdowns. The primary channel through which this demographic change operates is the employment-to-population ratio. We find that decreases in the employment-to-population ratio largely outweighed capital deepening induced by increased savings. Moreover, our model predicts that demographic change will cause growth to decline further over the next 20 years. This paper

[3] Cooley and Henriksen (2018) show the impact of changing demographics on growth in the U.S. and Japan but do not explicitly model the impact of retirement systems on individual decisions and economic growth.

complements the conclusions of Gordon (2016), Summers (2014, 2016), and others who study secular stagnation.

We also find that the need to finance pension systems did not lower long-run growth very much over the 1975-1995 period. Over the last 20 years, however, pension systems have decreased growth, sometimes substantially. In Italy, our model indicates that the need to finance pension outlays decreased annual growth by an additional 0.18 percentage points. Moreover, these distortions will decrease annual growth even further over the next 20 years, with labor supply accounting for most of the decline in projected growth. These results add to the extensive literature on the implications of ageing for the sustainability of social security systems, e.g. Fuster, İmrohoroğlu, and İmrohoroğlu (2007) and İmrohoroğlu, Kitao, and Yamada (2016), by emphasizing that labor-supply choices are critical and that the big outstanding question is why increases in longevity have not resulted in larger changes in the effective retirement age. [4]

To account for observed labor supply choices on both the extensive and intensive margin, a key ingredient in our model economy is the disutility of labor supply at different ages. Due to the stark decline in labor force participation at old ages, the disutility of labor must increase strongly at old ages. The convex nature of the disutility of labor may be due to both psychological factors– individuals may simply be tired of working after 30+ years in the labor force– or to physiological factors, e.g. declining health and fitness over the life-cycle. This paper is agnostic on the exact causes of the disutility of labor over the life cycle, but we calibrate our model to observed age specific labor force participation rates in each of the countries taking as given the pension system in those countries. This enables us to analyze the incentive effects of alternative pension systems. More importantly, it provides a laboratory to evaluate the welfare effects of possible reforms.

This paper also contributes to the literature on late-life labor supply. Erosa, Fuster, and Kambourov (2016) show that a fixed cost to participation is key for matching aggregate Frisch elasticities. Others, such as French (2005), van der Klaauw and Wolpin (2008), and Erosa, Fuster, and Kambourov (2012), argue that social security rules have a sizable impact on retirement behavior. Capatina (2015), Pashchenko and Porapakkarm (2017), and French and Jones (2011) instead study the role of health risk and show that it may be just as important as social security rules in accounting for labor supply choices. All of these papers, however, assume either a constant or linear cost to labor force participation, or allow individuals' time endowment to change only as a result of changing health status. As a result, they either have difficulty matching the labor force participation profiles of both healthy and unhealthy individuals after the age of 60+, or do

[4] A more exhaustive review of such papers includes, but is not limited to, Auerbach and Kotlikoff (1987), De Nardi, İmrohoroğlu, and Sargent (1999), Kotlikoff, Smetters, and Walliser (2007), Kitao (2014), Conesa and Garriga (2016), McGrattan and Prescott (2017), and McGrattan and Prescott (2018).

not attempt to match labor supply profiles that late in life. This, however, is a key part of the life cycle for understanding the effects of aging populations on economic growth and potential policy reforms to mitigate any adverse welfare effects.

Our paper is also related to Auclert, Malmberg, Martenet, and Rognlie (2019) and Börsch-Supan, Leite, and Rausch (2019), who study how changing age-cohort distributions may affect future growth, taking decisions as given. Kopecky (2018), Hopenhayn, Neira, and Singhania (2018), and others study how changing demographics may account for firm dynamics and the decline in entrepreneurial activity and, through that, productivity growth.

The rest of the paper is organized as follows. Section 2 describes the long term growth and demographic trends in France, Germany, Italy, and the United Kingdom. Section 3 describes our model along with two methods of financing our pension systems. Section 5 presents our historical decompositions, growth projections, and our pension reform experiments. Section 6 concludes.

2 Growth and Demographic Change

2.1 Historical Growth

The world's largest economies have experienced a growth slowdown over the last five decades. Figure 1 shows GDP-per-capita trends for the four largest European economies and the United States. In the two decades immediately following World War II, Germany, France, and Italy experienced significant catch up, in large part due to the build-up after wartime destruction. Our goal is to estimate the role that demographic changes may have played since the 1970s.

[Figure 1 about here]

We can decompose historical growth into its constituent components using growth accounting to determine the contributions of factor inputs and productivity using a standard Cobb-Douglas production function:

$$Y = A \cdot K^{\alpha} (L \cdot h)^{1-\alpha} \tag{1}$$

where A is TFP, K is the aggregate capital stock, L is the number of workers, and h is the average hours worked by those in the labor force.[5] This implies an expression for growth, which includes both an intensive and extensive labor-supply margin given by h and $\frac{L}{pop}$, respectively.

$$\gamma_Y = \gamma_A + \alpha\gamma_{K/L} + \gamma_{L/pop} + \gamma_{pop} + (1-\alpha)\gamma_h \tag{2}$$

In Equation 2, γ_i is the growth rate of component i. Population growth can trivially account for GDP growth and so we exclude it from the rest of our discussion, instead focusing on GDP-per-capita growth. The per-capita growth accounting expression then becomes

$$\gamma_{Y/pop} = \gamma_A + \alpha\gamma_{K/L} + \gamma_{L/pop} + (1-\alpha)\gamma_h \tag{3}$$

The annualized results of this exercise are shown in Table 1.

[Table 1 about here]

Growth accounting highlights both the persistence and heterogeneity across countries in the growth slowdown shown in Figure 1. Table 1 further shows that understanding the determinants of labor-supply is crucial for understanding the growth experience of these economies. In order to account for these facts, a low-frequency structural change that has first order implications for labor supply and differs across countries is necessary. One such factor is demographic change.

2.2 Demographic Trends

Life expectancy at birth among the advanced economies has increased steadily as shown in Figure 2. Life expectancy among these countries increased from an average of 72.5 to 77.3 and 77.3 to 81.8 between 1975-1995 and 1995-2015, respectively. UN projections continue this trend with a predicted rise from 82.7 to 85.5 between 2020 and 2040.

[Figure 2 about here]

[5] Our assumed capital share is consistent with that of our calibration discussed in Section 4

These dramatic changes in longevity combined with lower fertility has caused populations to age, some significantly. Figure 3 illustrates the historical shift in the age-cohort distribution for the United Kingdom, France, Germany and Italy, respectively, and how they differ. Two characteristics stand out. In all economies, population aging has persisted for several decades and is projected to continue. Second, the historical and projected rightward shifts in the age-cohort distribution differs across these four countries. The low frequency nature of these trends and their differences between countries implies that demographic factors may contribute to both the decline in long-run growth in each country and the different growth histories across countries.

[Figure 3 about here]

An often overlooked feature of the European experience is that, even as life expectancy has increased substantially, the average retirement age has not.[6] On average, individuals have predominantly allocated additional years of life to retirement.

[Figure 4 about here]

2.3 Growth and demographics

Increases in life expectancy and changes in the age-cohort distribution may affect economic growth through all the five channels identified by the growth accounting exercise in Equation 2.

Figure 5 shows that labor supply on the intensive margin shows a clear hump-shaped pattern over the life cycle across these European countries. If this hump shape remains unchanged, as the cohort distribution changes, hours will also change. In addition, labor supply choices on the intensive margin may change as life expectancy increases and factor prices change due to demographic factors.

[Figure 5 about here]

[6] While this has been historically true for the United States as well, Figure 4 shows that the increase in the gap between effective retirement age and life expectancy has been considerably smaller and has remained roughly constant since the mid to late 1990's.

Almost the same mechanisms hold for labor supply on the extensive margin. Figure 5 also shows a clear hump-shaped pattern of labor force participation over the life cycle across these European countries. The number of individuals in the labor force will therefor be directly affected by shifts in the cohort distributions. In addition, labor supply choices on the extensive margin may also change as life expectancy increases and factor prices change due to demographic factors.

As the average age increases, more individuals will be in their wealthiest years. In order to smooth consumption over a longer expected lifetime, individual savings rates may increase. Both demographic factors shaping individual choices and the aggregation of these choices contribute to capital deepening, ie. increase in the capital-to-labor ratio.

Aging populations affect measured TFP. As populations age, the fraction of the workforce in the most productive years of their lives also changes. Since productivity is measured conditional on number of hours worked, this affects measured TFP.

In addition, the more individuals who have chosen to retire relative to the number of individuals who have chosen to work, the higher are the taxes necessary to finance pensions and other programs supporting retirees. These taxes will distort labor-supply choices both on the extensive and intensive margin.

All of these factors, both direct and indirect, affect equilibrium prices through the aggregate capital stock and labor supply, which further affects individual incentives and output.

3 Model

Our model economy is as parsimonious as possible while addressing all the five growth channels identified by the growth accounting exercise. In particular, individuals make labor-supply choices on both extensive and intensive margin and savings choices over the life cycle. In order for the model to match observed retirement behavior, we assume that disutility of working is increasing with age. In order to distinguish between labor-supply choices on the intensive and the extensive margin, the model is calibrated to idiosyncratic shocks to labor productivity over the life cycle.

The benchmark economy abstracts from pensions. In this economy, individuals fund their own retirement consumption by savings. Subsequently, we introduce a pension system where old age benefits are financed by workers with either lump sum or distorting taxes. We decompose the growth effects of demographic change into a direct effect and an indirect effect, operating through the increasing wedges necessary to finance increasing pension outlays. These environments allow us to discuss the extent to which pension systems impose additional obstacles to growth and identifies the margins most affected by them.

3.1 Households

At each age, i, households maximize their expected discounted utility by choosing consumption and labor supply conditional on their life expectancy

$$\max_{\{c_j,h_j\}} \mathbb{E}_t \sum_{j=i}^{I} s_j u(c_{j,t+j}, h_{j,t+j}) \tag{4}$$

where β is the household's discount factor, s_i is the probability that a household lives from age i to $i+1$, and c_i and h_i are consumption and hours worked at age i, respectively. Household preferences are assumed to be additively separable both within and across periods and take the iso-elastic form given by

$$u(c,h) = \frac{c^{1-\sigma}}{1-\sigma} + \chi \frac{(1-h-\theta_i \cdot I_p)^{1-\gamma}}{1-\gamma} \tag{5}$$

Here, σ denotes the elasticity of intertemporal substitution, $l = 1 - h - \theta_i \cdot I_p$ is effective leisure, and γ defines the curvature over effective leisure. I_p is an indicator function that takes a value of 1 if $h > 0$ and 0 otherwise. Households' cost to participation, θ_i, is allowed to differ by age and is given by the following functional form.

$$\theta_i = \kappa_1 + \kappa_2 \cdot i^{\kappa_3} \tag{6}$$

This cost function may capture a number of life-cycle features, such as deteriorating health, changes in tolerance to fatigue and stress, and other life-cycle incentives, such as retirement systems. The labor supply literature has largely emphasized the first and last of these three considerations. French (2005) and Capatina (2015), for example, evaluate the role of deteriorating health in late life labor supply. They assume that the cost to participation differs between sick and healthy individuals, but each is fixed over the life cycle. Instead, they allow the probability of negative health to increase with age. Related are Rust and Phelan (1997), Blau and Gilleskie (2006, 2008), and French and Jones (2011) who estimate the retirement incentives induced by medicare and employer provided health insurance. While their findings are mixed, they all find that health insurance can at least partially account for observed retirement behavior. Our specification is appealing as it captures all of these features while preserving the parsimony of our model. Most importantly, however, it can be easily matched to old age labor force participation rates.

The households maximize expected discounted utility subject to their budget constraint, which is given by

$$c_{i,t} + a_{i+1,t+1} = (1 + r_t)a_{i,t} + w_t \cdot h_{i,t} \cdot \psi_i \cdot \eta_{i,t} + b_t \tag{7}$$

c is consumption, a is asset holdings, r is net rate of return on capital, w is hourly wage rate, h is number of hours worked, ψ is age-dependent productivity, η is the households idiosyncratic productivity, and b is accidental bequests. To close the model, we assume that accidental bequests, b_t, from households that exit the model as a result of mortality risk are evenly distributed among all surviving households.

We further assume that households begin their economic lives with no assets and enforce a no-ponzi condition, producing an initial condition and boundary condition given by

$$a_{i_0,t} = 0 \qquad \text{and} \qquad a_{i_{max},t} \geq 0 \tag{8}$$

where i_{max} is the maximum allowed age. We maintain (8) throughout the paper.

Households differ both between and within cohorts in several ways. First, household productivity differs between cohorts due to an age specific productivity profile, ψ_i, and within cohorts as a result of idiosyncratic labor productivity shocks. We assume that the idiosyncratic component of individual productivity follows an AR(1) process in logs for each individual given by

$$\ln \eta_{i+1} = \rho \ln \eta_i + \epsilon_{i+1} \tag{9}$$

where $\epsilon_i \sim \mathcal{N}\left(0, \sigma^2\right)$ is Gaussian white noise. These two sources of heterogeneity create differences in average hours worked between cohorts and hours dispersion within cohorts, respectively. In particular, these productivity differences incentivize households who are in the most productive years of their lives or who have received a series of high productivity draws to work more hours.

Households also face an endogenous and irreversible retirement decision each period. Consistent with Erosa et al. (2016) and Rogerson and Wallenius (2013) who show the importance of a fixed cost to work in accounting for labor supply elasticities and retirement, the interaction between our cost to participation function, θ_i, and life cycle productivity profile, ψ_i, generate heterogeneity in labor force participation rates between cohorts.[7] As discussed in Section 4, our calibrated cost to participation function is increasing in age while our life-cycle productivity profile is hump shaped. Labor force participation rates, therefore decrease over the life cycle since it becomes more costly to remain in the labor force and households are less productive on average at old ages.

[7] More precisely, Rogerson and Wallenius (2013) emphasize the need for non-convexities in either individual budget constraints or choice sets to generate reasonable intertemporal elasticities of labor.

The interaction between Equation 9 and Equation 6, further provides a mechanism within our model to generate endogenous workforce composition. As θ_i increases with age, households who have received a series of poor idiosyncratic productivity shocks become less likely to remain in the workforce. As a result, only the most productive households continue working at old ages. This both creates within cohort differences in labor force participation and makes our model consistent with papers showing that life-cycle earnings is flatter than life-cycle productivity, e.g. Rupert and Zanella (2015).

3.2 Technology

We assume that a representative firm with constant returns to scale Cobb-Douglas production technology demands capital and labor, and produces a numeraire good for consumption in perfectly competitive markets. Thus, the firm's problem is given by

$$\max_{K_{d,t},L_{d,t}} \left\{ K_{d,t}^{\alpha} L_{d,t}^{1-\alpha} - (r_t + \delta) K_{d,t} - w_t L_{d,t} \right\} \tag{10}$$

where $0 < \alpha < 1$ is capital share, $K_{d,t}$ is aggregate capital demand, $L_{d,t}$ is aggregate labor demand measured in efficiency units, r_t is the net real interest rate, and w_t is the real wage rate. Moreover, the aggregate capital stock evolves according to the usual law of motion,

$$K_{t+1} = (1 - \delta) K_t + I_t \tag{11}$$

where δ is the depreciation rate and I_t is net investment.

3.3 General Equilibrium

An equilibrium in this environment is defined as follows:

1. Households choose savings, consumption, and labor supply on the extensive and intensive margins taking prices and conditional survival probabilities, s_i, as given such that

- Household's solve the following recursive problem each period:

$$v_{LF}(i,a,\eta) = \max_{c,a',h} \left\{ u(c,h) + \beta \cdot s_i \cdot \mathbb{E}_{\eta'|\eta} \max \left\{ v_{LF}(i+1,a',\eta'), v_R(i+1,a') \right\} \right\}$$

$$v_R(i,a) = \max_{a',c} \left\{ u(c,0) + \beta \cdot s_i \cdot v_R(i+1,a') \right\}$$

- Decisions are aggregated to get the aggregate supply of capital and labor measured in efficiency units:

$$K_{s,t} = \sum_i x_i \cdot \int_{a\times\eta} a \cdot \mathrm{d}\mu(a,\eta \mid i,t)$$

$$L_{s,t} = \sum_i x_i \cdot \int_{a\times\eta} h \cdot \psi_i \cdot \eta \cdot \mathrm{d}\mu(a,\eta \mid i,t)$$

  where x_i is the fraction of the population constituted by cohort i and $\mu(a,\eta \mid i,t)$ is the stationary joint distribution of a and η in time t for cohort i.

2. Firms maximize profits taking prices as given:

$$\max_{K_{d,t},L_{d,t}} \left\{ K_{d,t}^{\alpha} L_{d,t}^{1-\alpha} - r_t K_{d,t} - w_t L_{d,t} \right\}$$

3. Markets clear:

$$\{r_t, w_t\} \mid K_{s,t} = K_{d,t} \;\; \& \;\; L_{s,t} = L_{d,t}$$

3.4 Demographics

Our definition of general equilibrium shows that the conditional survival probability at each age, s_i, and the age-cohort distribution, x_i, in each period are sufficient statistics to capture demographics within our model. Several factors influence the evolution of a country's age-cohort distribution. First, changes in mortality rates reduce the number of deaths per year. Second, declines in a country's fertility rate reduces the degree to which aging cohorts are replaced by new, younger individuals. Both of these effects serve to shift the age-cohort distribution right. Lastly, a country's cohort distribution is affected by net migration flows, thereby shifting the cohort distribution either left or right depending on the mix of migrants.

Let $x_t \in \mathbb{R}^I$ denote the vector of length I where each element contains the fraction of the population of age i at time t. Each cohort is endowed with an age specific fertility rate, $f_{i,t}$, and a conditional survival probability, $s_{i,t}$, in each period. Moreover, denote $m_t \in \mathbb{R}^I$ as the vector of net migration of each age group in period t. Then the evolution of the cohort distribution within a given country is given by

$$x_{t+1} = \Gamma_t x_t + m_t \tag{12}$$

where,

$$\Gamma_t = \begin{bmatrix} f_{1,t} & f_{2,t} & f_{3,t} & \dots & f_{i,t} \\ s_{1,t} & 0 & 0 & \dots & 0 \\ 0 & s_{2,t} & 0 & \dots & 0 \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & \dots & s_{I-1,t} & 0 \end{bmatrix} \tag{13}$$

Note that the cohort distributions used in our quantitative exercise do not necessarily equal the stationary distribution implied by Γ_t. Instead, we assume that individuals believe that the current demographic structure and therefore prices will persist in perpetuity. Results should be interpreted as calculating steady states implied by each point along the demographic transition path.

Our model consists of I overlapping generations. We assume that households are ex-ante identical, enter their independent economic lives at age 20, and that no individual can live past age 100. Prior to age 20, households do not work, accumulate assets, or consume. Moreover, all households are born with $a_{i_0} = 0$ net assets.

At each age, i, households face mortality risk. Denoting s_i as the probability of surviving to age $i+1$ conditional on reaching age i, the unconditional probability of reaching age j is given by $s^j = \prod_{i=1}^{j-1} s_i$. These survival probabilities capture changes to life-expectancy within our model and distort the discount rate at each age. Upon death, any assets saved from age i to $i+1$ are transferred equally across the remaining population in the form of lump sum accidental bequests, b_t.

3.5 Pension Systems

To quantify the implications of public defined-benefit pensions and their financing, we introduce a parsimonious pension system with guaranteed old age benefits. Here, we assume that households believe that current pension systems will persist indefinitely and that taxes are adjusted to balance government budgets period-by-period. For computational simplicity, we take the level of real pension benefits to be constant and equal for each eligible household across cohorts above some eligibility age, I_R. In particular, define $\tau_{L,t}$ and t_t to be the labor tax rate and lump sum taxes levied on households, respectively, at time t. The household budget constraint then becomes

$$c_{i,t} + a_{i+1,t+1} = (1-\delta)a_{i,t} + r_t \cdot a_{i,t} + (1-\tau_{L,t}) \cdot w_t \cdot h_{i,t} \cdot \psi_i \cdot \eta_{i,t} + b_t - t_t \cdot \mathbf{1}(i < I_R) + p_t \cdot \mathbf{1}(i \geq I_R) \quad (14)$$

where p_t is the level of real pension benefits and with r_t re-defined to be the marginal product of capital rather than the net real interest rate. Moreover, we assume that lump sum taxes are levied only on those who are not eligible for old age benefits so that net transfers received in old age are not distorted by the financing of pension benefits. To close the model, define the budget constraint of the government to be

$$\sum_{i \geq I_R} \mathbf{x}_i \cdot p_t = \tau_{L,t} \cdot w_t \cdot L_t + T_t \quad (15)$$

where T_t denotes total lump sum tax revenues and where we have assumed that there is no additional government spending outside of pension outlays.

Pension systems have important implications for individual decisions, particularly household labor supply. First, incentives to accumulate assets and work later in life as life expectancy increases is mitigated relative to a world without pension systems as individuals may rely on social security in addition to individual savings to smooth consumption. Second, as a larger fraction of the population enters retirement, these pension systems create significant disincentives to work. As populations age, a greater number of households become eligible for benefits causing total pension outlays to increase. If increases in life expectancy do not translate into large increases in labor force participation at old ages, the tax base will decrease and force tax rates to rise. The changes in these tax rates provide greater disincentives to work as populations age and result in even smaller increases in retirement ages as life expectancy rises.

3.6 Importance of Labor-Supply Decisions

To illustrate the importance of labor supply decisions in our framework, we solve a special case of our model with inelastic labor supply. In contrast to our benchmark model, the vast majority of the literature investigating the consequences of aging populations assumes that labor is supplied inelastically until a given retirement age. Key results, such as secular decline in interest rates, rest on this particular assumption.

The focus of literature studying demographic change has largely been on its effects on the supply and demand for capital. The general assumption has been that labor is supplied inelastically until some exogeneous retirement age. The implicit assumption is that retirement age does not change as life expectancy rises. That is to say that gains to longevity, both in the past and in the future, will translate one-for-one into more years spent in retirement with no adjustment to individual work behavior. Understanding how labor supply decisions change as expected longevity and factor prices change are not only of crucial importance for making projections for future real interest rates, but also for making growth projections and estimating the welfare effects of potential reforms.

To illustrate the sensitivity of previous results to the assumptions made about labor supply, we solve a simplified version of our model that reflects those used in the literature. We assume that households make only a consumption-savings choice, are identical within cohort, and supply labor inelastically until an exogenously given retirement age. At retirement they exit the labor force and collect social security. In effect, this model is identical to our model after fixing $\{\eta_i, \psi_i\} = \{0, 1\}\ \forall i$ and $\chi = 0$. The rest of our model environment is left unchanged. At the benchmark, life expectancy and the exogenous retirement age are first set to 70 and 65, respectively. We then increase life expectancy to 80 years, solve the model for retirement ages between 65 and 75, and compare the model-implied equilibria with the benchmark.[8] The range of retirement ages represent the entire range between two extremes: i) Retirement age does not adjust at all in response to gains to life expectancy and remains at 65 years. All gains to longevity translate one-to-one to more years in retirement. And ii), retirement age adjusts one-for-one with life expectancy, while expected time in retirement remains the same.

[Figure 6 about here]

Figure 6 shows the growth in output, change in equilibrium interest rate, and change in the equilibrium labor tax rate necessary to finance pension outlays relative to the first extreme. Clearly, the conclusions drawn are both quantitatively and qualitatively sensitive to assumptions regarding labor supply. In fact, output growth, the change in real interest rates, and the change in budget balancing tax rates may all be positive or negative depending on what assumptions are made. All results would change sign if time in retirement, instead of length of working lives, was held constant. In particular, interest rates would increase if retirement age increases by just six years when life expectancy increases by ten years. This exercise highlights that a key margin necessary to understand the effects of demographic change is individual labor supply.

[8] Cohort distributions are given by the steady state distributions implied by each life expectancy at birth.

4 Calibration

We calibrate our benchmark model and pension systems separately for Italy, Germany, France, and the United Kingdom by fixing several preference and production parameters, estimating the age-cohort distributions, survival probabilites, and productivity parameters outside the model, and using simulated method of moments for the remaining parameters. Our calibration target year is 1995 due to the availability of data. The key margins of our model are the labor supply elasticities on both the intensive and extensive margin, particularly at old ages, and tax rate elasticities.

4.1 Preference Parameters

We first set $\sigma = 1$ in order to obtain balanced growth preferences as in King, Plosser, and Rebelo (1988) and fix the curvature on leisure to be $\gamma = 4$. The remaining preference parameters are the discount factor, β, household's weight on leisure, χ, and the cost to participation parameters, κ_1, κ_2, and κ_3. We set β to match the measured capital-output ratio for each country, which is calculated from the Penn World Tables 9.0 release through the FRED database. χ is targeted to a weighted average of hours worked per year by working households aged 20-64 from the OECD statistical database. The weights are given by the relative size of the workforce at each age. Because of the importance of labor-supply decisions on the extensive margin in driving our results, our goal is to tightly link our cost to participation parameters, $\{\kappa_1, \kappa_2, \kappa_3\}$, to retirement decisions at the end of life. To do so, we calibrate these parameters to match labor force participation rates of those aged 60-64 and 65-69, and the effective retirement age calculated as in Keese (2003).[9] Data for each is obtained from Eurostat and the OECD statistical database, respectively. Finally, we restrict participating households to work no less than 20% of their available time.

4.2 Technology and Productivity

Our production technology is Cobb-Douglas form with a capital share of $\alpha = 0.33$. While standard measures of capital share show significant heterogeneity across economies, Gollin (2002) shows that capital shares are in fact quite stable in the cross section after controlling for self-employed income. Our chosen value reflects his mean estimate. We set the depreciation rate, δ, to match the 1995 real interest rate in each country, where we calculate the real interest rate as the return on 10

[9] The effective retirement age we use is a weighted labor market exit age starting at age 40, where the weights are the change in labor force participation from age i to $i + 1$.

year long-term government bonds less inflation. Each is taken from the OECD and World Bank, respectively, through FRED. As in Hansen (1993), we estimate the life-cycle productivity profile and idiosyncratic productivity process from the PSID.[10] Figure 7 shows our estimate for ψ_i, and we find the persistence and variance of the idiosyncratic productivity process to be $\rho = 0.97$ and $\sigma^2 = 0.02$, respectively.

[Figure 7 about here]

4.3 Pension System

There are important differences in the public pension systems of the four European Economies we study. These are discussed extensively in Erosa et al. (2012) and in SHARE, the Survey of European Health and Retirement systems. For our purposes the important features of pension systems that largely drive changes in tax rates and retirement incentives are the eligibility age, I_R, and the level of real old age benefits, p. The former is taken from the Blondal and Scarpetta (1997) and Gruber and Wise (1999). In order to calibrate p_t, we match the level of pension expenditures in the form of non-means tested old age benefits by country as a percentage of GDP and assume that these old age benefits are evenly distributed among the eligible population. This data is obtained from Eurostat. We allow only one form of taxes to balance the government budget constraint at any given time. Consequently, we calibrate two models with pension systems: a lump sum model and a labor tax model. In our quantitative experiments, we fix p_t and allow the relevant tax rate to adjust to close the model. Finally, note that we fix $p_t = t_t = \tau_{L,t} = 0$ in our benchmark model without pension systems.

4.4 Demographics

What remains is to calibrate the survival probabilities and relative size of each age-cohort in each country. The cohort distributions are taken from the United Nations (2017), which gives the cohort distribution in 5 year age bins. We linearly interpolate between the center of each age bin and re-normalize the interpolated distribution to obtain 1 year cohort bins. The interpolated cohort distributions are shown in Figure 3.

[10] A similar data set is not readily available to us for the four countries herein considered.

The one-year survival probabilities are calculated as in Henriksen (2015) using life expectancy data obtained from the United Nations. These estimates are shown in Figure 8 and incorporate the fact that mortality rates are a function of both age and life expectancy at birth.

The set of moments matched for each country are summarized in Table 3. Appendix B gives the corresponding model moments, calibrated parameters, and fixed parameters for each country. Of particular note are our calibrated cost to participation functions. For each model and each Country, $\{\kappa_1, \kappa_2, \kappa_3\}$ are broadly consistent with French (2005) and Capatina (2015). Both estimate that the life-cycle probability of poor health is increasing and approximately convex in age with the latter further showing that individual time endowment decreases in expectation over the life-cycle.

[Table 3 about here]

5 Quantitative Results

In our quantitative exercise, we fix the calibrated parameters of the model and adjust the conditional survival probabilities and cohort distributions to match those in 1975, in 1995, and in 2015. We then perform growth decompositions from 1975-1995 and 1995-2015 by applying the growth accounting methodology in Equation 2 to the model steady states. Finally, we make growth projections by repeating the above exercise for 2020 and 2040. We conclude this section with a discussion of the effects of pension reforms and innovations to factors captured by our cost to participation function.

5.1 Direct Effect of Demographics

We first decompose the per-capita growth effects of demographic change using the benchmark model. Table 4 displays a summary these effects in the benchmark model. It highlights the changing contribution of aging populations to growth relative to the growth slowdown discussed in Section 2.

[Table 4 about here]

While aging populations substantially boosted growth during the 1975-1995 period, their contributions to growth declined throughout the following two decades in all countries considered. Our model indicates that the changing historical contribution of demographic change to growth is responsible for a decline in annual per-capita growth of 0.33-0.68 percentage points between these two periods. Relative to our growth accounting exercise in Section 2, our benchmark results suggest that aging populations account for roughly 70% of the secular growth slowdown in Germany and France, 46% in the United Kingdom, and 27% in Italy.

[Table 6 about here]

To explore the channels through which aging populations effect growth, we focus our discussion on the past 20 years. Table 6 shows that demographic change was a drag on per-capita growth for France, Germany, and Italy while it contributed positively in the United Kingdom. The primary channels through which this effect operates are through changes in labor supply on the extensive and intensive margins and, to smaller degree, through capital accumulation. Indeed, the combination of increases in life expectancy and rightward shifts in the age-cohort distribution leads to capital deepening. These increases in the aggregate capital stock result in significant declines in equilibrium interest rates ranging from 81 basis points in the case of Italy to 43 basis points in United Kingdom. r^* changes between 1975 and 2015: UK: 43 basis points, IT: 81 basis points, GE: 75 basis points, and FR: 75 basis points.

Labor supply is affected along both the intensive and extensive margins. As workforces age, the average cost of participation incurred by households also rises. The overall effect is that hours worked decreases.

Changes in the employment-population ratio have the largest effect on growth. Over the past 20 years, aging has caused substantial declines in the labor force participation rate. As in the case of labor hours, rightward shifts in the cohort distribution have resulted in a larger fraction of the economically active population being in the right tail of the age-cohort distribution. Older households face strong incentives to retire due to both a higher cost to participating in the labor force and declines in life-cycle productivity at old ages. Conversely, gains to life expectancy incentivize households to increase labor supply at old ages. This endogenous response works to mitigate declines in labor supply as age cohort distributions shift. For example, between 1995 and 2015, the effective retirement age in each country increased by: UK: 0.93, IT: 1.58, GE: 1.23, and FR: 1.21. In comparison, life expectancy at birth over this same time period increased by an average of 4.5

years across these economies. As discussed above, shifts in the age cohort distribution outweighed increases in effective retirement ages with the net effect of declining labor force participation.

Demographic change also affected measured total factor productivity. Due to our hump shaped life-cycle productivity profile, young populations that age begin to have a larger share of their workforce in the most productive periods of their lives. Thus, aging populations affect measured TFP mechanically through shifts in the age-cohort distribution.

Measured TFP is also affected by an endogenous mechanism briefly discussed in Section 3. Due to the persistence of idiosyncratic productivity shocks and rising cost to participation, there are strong self selection effects with respect to labor force participation. In particular, those who have received a series of high productivity draws early in life are more likely to remain in the labor force at older ages.

Strong general equilibrium effects further effect all of these margins. As relative prices change, so too do the incentives to accumulate capital and supply labor. Changes to the latter are of particular importance given our results. For example, changes in the wage rate directly affect the level of individual productivity required to remain in the workforce at old ages. Labor force participation rates and the composition of workers are in turn affected. In this case, the negative labor supply effects described above are partially offset by rises in the wage rate induced by capital deepening.

Over the next two decades, our model predicts that the contributions of demographic change to per-capita growth will decline further. Indeed, Table 7 shows that decreases in the employment-population ratio are projected to become more prominent while capital deepening will decelerate. The benchmark model indicates that Germany and Italy will face the most significant declines to future growth.

[Table 7 about here]

5.2 The Effect of Pension Systems

Next, we compare the growth accounting exercise discussed in the previous section to a model with pensions that are funded with lump-sum taxes. Because lump-sum taxes are non-distortionary in nature, this comparison allows us to estimate how old-age transfers alone impact growth. We subsequently describe our results when such transfers are funded by a labor income tax, allowing us to estimate the growth effects of increasing distortions that result from pension systems.

Quantitatively, the provision of old-age transfers themselves create few declines in growth. While small, these effects are most strong in Italy. Old-age benefits provide elderly households with additional resources from which to consume. Thus, retired households may rely on social security in addition to individual savings to smooth consumption throughout retirement. This mitigates incentives to increase savings and labor supply resulting from gains in life expectancy.

The distortions arising due to these pension outlays, on the other hand, have important implications for growth. As populations age, fiscal authorities face increasing liabilities in the form of social security payments. Table 8 show just how drastically pension outlays increase in response to aging in our model. Given the declines in labor supply identified in Section 5.1, tax rates must increase to balance budgets. The rise in labor tax rates in turn provide strong disincentives to work, further decreasing labor supply and compounding the problem faced by fiscal authorities.[11]

[Table 8 about here]

The quantitative effect of these distortions are shown in Table 5, Table 6, and Table 7. These distortions were quantitatively unimportant during the 1975-1995 period. Because a large number of previously inactive households began entering the labor force during this period (see Figure 3), increases in labor supply provided sufficient tax revenue to remove the need to increase tax rates. Thus, pension systems did not greatly impact growth during 1975-1995.

Over the past two decades, changing demographics imply that there were fewer new workers and more workers in retirement. As a result, tax rates rise sharply to cope with changing pension obligations. These additional distortions amplify the rise in retirement rates relative to the benchmark and lump sum models. Between 1995 and 2015, effective retirement ages increased by substantially less than in the benchmark model: UK: 0.48, IT: 0.79, GE: 0.71, and FR: 0.64. This endogenous response of old-age labor supply is roughly half of that in the benchmark model. The end result is that annualized growth in the employment/population ratio decreased by an additional 10 basis points in France, Germany, and Italy as a direct result of changing tax rates. The effect in the United Kingdom is smaller, at around 4 basis points.

Rising tax rates also affect capital deepening. Not only does the duration of households' working lives decrease relative to a world without such distortions, but so too does after tax labor income conditional on working. Both features directly effect the resources from which households save.

[11] Conesa, Kehoe, Nygaard, and Raveendranathan (2019) suggest that trends in college attainment may mitigate the need to increase tax rates.

The end result is a decline in capital accumulation. Moreover, pension systems dampen the decline in interest rates previously discussed through this channel. In this case, declines in the equilibrium interest rate instead range from 21 basis points to 50 basis points.

While the effects are smaller, these changing distortions also affect measured TFP growth. As labor taxes rise, the individual productivity level needed to remain in the workforce during old age does as well. Thus, the workforce that remains following a rise in labor taxes is more productive. This amplifies the self-selection mechanism in the model.

All of these effects contributed to a growth decline resulting from pension systems. In total, changing tax rates decreased annual growth by between -0.04 percentage points in the case of the United Kingdom and -0.18 percentage points in Italy throughout the 1995-2015 period. Our model further predicts that the growth effects of these distortions will become much stronger over the next 20 years.

5.3 Policy Reforms

Given the sizable labor supply effects of aging populations, we now consider why individuals exit the labor force when they do and how these considerations affect the economy as a whole. Understanding these choices allows us to identify policy reforms that may both mitigate the negative growth effects of future demographic change and improve welfare. We stress the latter and rely on welfare effects measured by the median consumption equivalence of a newborn agent as a measuring stick. Our definition of consumption equivalence is given by

$$\mathbb{E}_{i_0} \sum_{t=i_0}^{I} \beta^t s_t u(\lambda_j c^*_{t,j}, h^*_{t,j}) = \mathbb{E}_{i_0} \sum_{t=i_0}^{I} \beta^t s_t u(c^{**}_{t,j}, h^{**}_{t,j}) \tag{16}$$

where λ_j is the consumption equivalence for household j, $\{c^*_{t,j}, h^*_{t,j}\}$ are their pre-reform optimal choices, and $\{c^{**}_{t,j}, h^{**}_{t,j}\}$ are their post reform optimal decisions. Straightforward algebra allows for a simple expression of the consumption equivalence for individual j defined by

$$\lambda_j = e^{\left[V_{j,post} - V_{j,pre}\right]/\phi} \tag{17}$$

where $\phi = \sum_{t=i_0}^{I} \beta^t s_t$, $V_{j,post}$ is the post-reform value function for newborn j, and $V_{j,pre}$ is the pre-reform value function for newborn j.

We first assess the role of pension systems in driving decreases in the employment-population ratio. Decreasing the level of old age benefits forces households to rely more heavily on individual savings during retirement. Households may therefore increase labor supply to finance savings increases. Raising the eligibility age incentivizes a longer working life directly. Because households must wait longer to receive any social security payments, households may increase their labor market exit age to avoid a period of low consumption between retirement and social security eligibility. Furthermore, both reforms decrease the fiscal authority's total pension obligations, reducing the degree to which tax rates rise to balance budgets. We consider these reforms by separately reducing per-retiree pension outlays by 5%-20%, and increasing the pension eligibility age increases by 5 years by the year 2040.[12]

Table 9 shows a summary of the effects of reducing the level of pension benefits received when in retirement. Evidently, such a reform mitigates the projected adverse growth effects of aging populations. Table 15 shows that the need to rely more heavily on personal savings to finance old age consumption causes savings rates to become more sensitive to changes in life expectancy. Second, the indirect effect pension systems on individual decisions through tax rates becomes weaker. The reduction in benefits reduces the need to raise tax rates, which in turn provides fewer disincentives to work. Relative to the pre-reform economy, the effective retirement age of households can increase substantially depending on the extent of the reform. Table 15 further shows that the labor supply channel is again much more important than individual savings.

More importantly, these reforms are welfare improving. The welfare effects of reductions in pension benefits may be significant as distortions to individual incentives begin disappearing depending on the extent of the reform. In France, Germany, and Italy, the median per-period consumption equivalent for newborns quickly rises over 1% as the extent of the reform increases. For significant benefits reductions, median per-period consumption equivalents range from 2.38%-4.16%. The United Kingdom sees more modest welfare gains with consumption equivalence, reaching a peak of 1.59%.

[Table 9 about here]

Except for conservative reductions in pension benefits, Table 10 identifies that increasing the pension eligibility age yields similar increases in annual growth. Increasing the eligibility age operates through similar channels as reductions in pension benefits. Table 16 displays the effects of eligibility reform in detail. First, as the eligibility age increases, social security does not become available to households until a later age. This implies that agents must rely more heavily on labor

[12] We discuss these reforms for the labor tax model only as the lump sum model features no distortions

income and private savings for these additional years before they become eligible for pension benefits. Second, as less of the population is eligible for any given level of benefits, government outlays and thus tax rates again increase by less as populations age. These two effects serve again to increase capital accumulation as life expectancy increases and mitigate the reduction in the employment to population ratio as populations age. In the case of increasing eligibility ages, increases in both growth and the effective retirement age are larger than that for most reductions in pension benefits. Despite this fact, the welfare gains from reductions in pension benefits are larger than increases in the pension eligibility ages, a direct result of sharp increases in the dis-utility of labor experienced by households at old ages.

[Table 10 about here]

This highlights the fact that the growth and welfare effects of pension reforms are limited by other factors that incentivize retirement. Two important components emphasized previously are health and fitness. These forces are captured by the cost to participation function in our model. Improvements in health, for example, directly affect our cost to participation function and therefore labor supply choices. We estimate the role of these issues by assuming that future gains to life expectancy are accompanied by equivalent gains to health, i.e. rightward shifts in our cost to participation function. Implementing innovations to health therefore require shifting the cost to participation function by 3 years.

[Table 11 about here]

Table 11 suggests that innovations to health and fitness captured by our quantitative experiment provide substantial welfare improvements. The per-period consumption equivalence for the United Kingdom are larger than the highest welfare gains in any of pension reforms. The same is true in France, Germany, and Italy for all but the largest cuts in pension benefits. In all four countries, the gains to projected growth and increases in the effective retirement age outpace that of any pension reform considered. Table 17 shows that the additional gains to growth are largely a result of increased labor force participation rates and longer average hours worked. These results further highlight the importance of labor supply decisions and life-cycle (dis-)incentives to work for estimating the effects of demographic change.

6 Conclusion

In this paper, we have asked to what extent demographic trends affect economic growth in the four largest European Economies: France, Germany, Italy, and the United Kingdom. We use a general equilibrium model with a rich demographic structure and funded pension systems to capture the impact of ageing on changes in factor supplies. We find that the demographic transition can account for a significant fraction of the historical growth slowdown in these economies, and that evolving demographics will continue to drag down growth over the next 20 years.

Our model framework shows that the large gains to life expectancy are economically more important than declining fertility. Increases to longevity change individuals' savings and labor supply decisions over the life cycle. Changes in longevity are also quantitatively more important than fertility for both the number and the proportion of the population in advanced ages where they have accumulated the most assets, where labor market decisions change, and where retirement is spent.

Much of the previous literature has focused on how demographics may change the equilibrium in the market for capital, assuming that labor is supplied inelastically and that gains to longevity do not change the length of working lives. In contrast we highlight that the most important consequences for growth may come from how gradually higher individual life expectancy changes labor-supply decisions on both on the intensive and extensive margin.

With our baseline calibration, increases in life expectancy translate mostly into longer individual time in retirement. Increases in life expectancy will also, mechanically, imply that the average age will increase. An indirect consequence of individuals choosing to spend more time in retirement and an increase in the number of individuals in the age groups that choose to reduce their labor supply or retire, is that equilibrium tax rates must rise sharply to balance budgets. These higher taxes further distort the participation decision of households.

To account for labor supply decisions on the intensive and extensive margin, we employ a reduced-form function that is convex in age to capture the cost of labor market participation. This is calibrated to match historical moments. This functional form allows us to make projections for future factor supplies and economic growth; gives us a laboratory to evaluate economic reforms to increase growth; and allows us to change the measure of such reforms from a pecuniary measure to a welfare measure.

This paper underscores that a hugely important outstanding question is to acquire an even deeper understanding of individuals' late-life labor supply and retirement decisions as life expectancy changes. If retirement decisions are mainly due to incentives from government programs, there may be both huge output and welfare gains from reforming those systems. If instead households face strong intrinsic preferences against working at old ages, seemingly obvious policy reforms, like increasing the threshold retirement age, may turn out to be welfare decreasing.

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A Figures

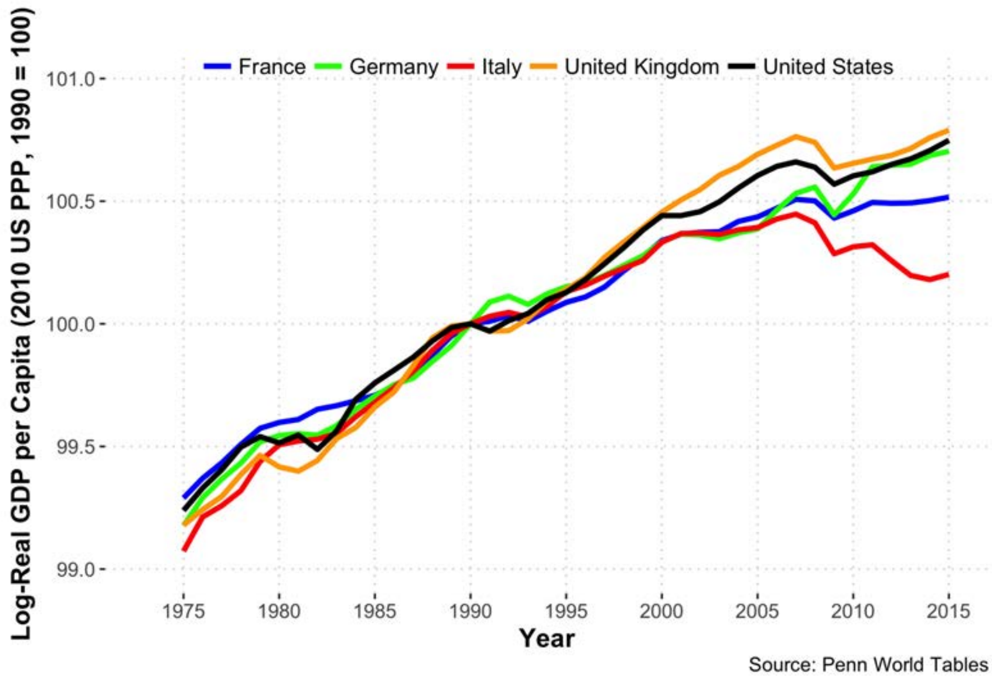


Figure 1: Real GDP per Capita in G7 Economies Excluding Canada and Japan

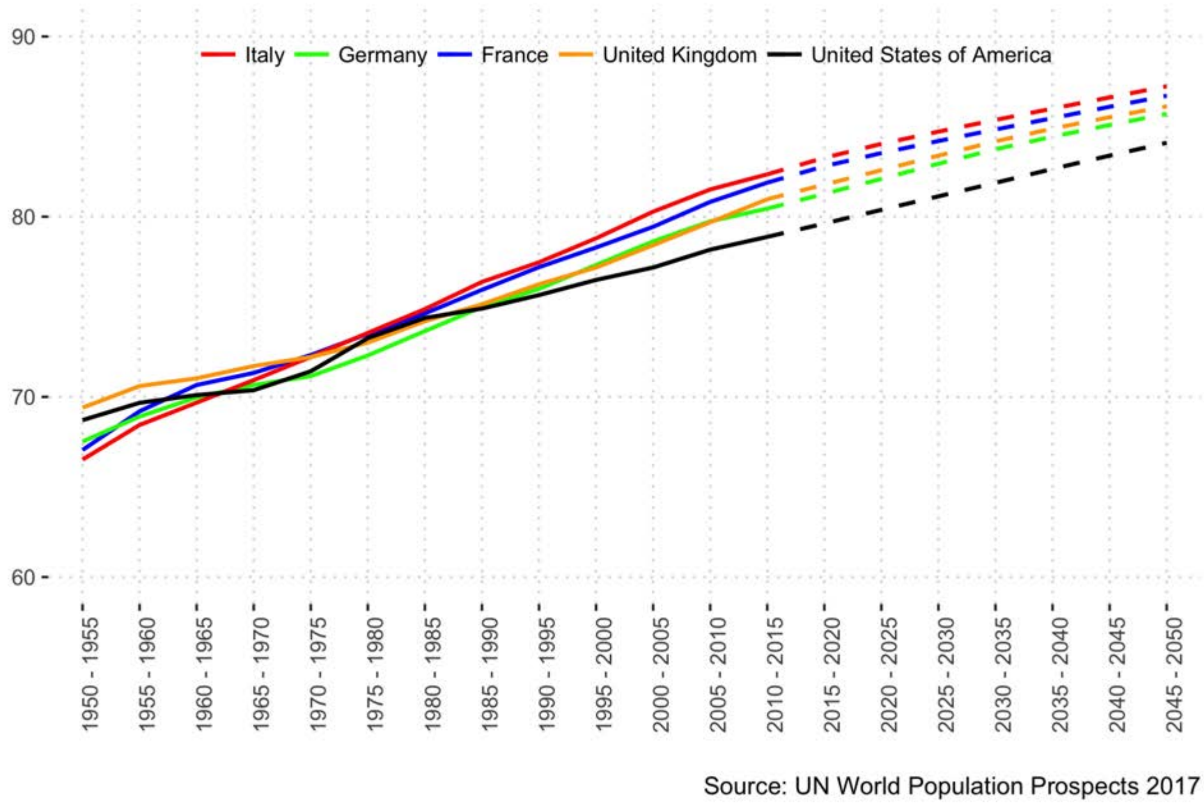
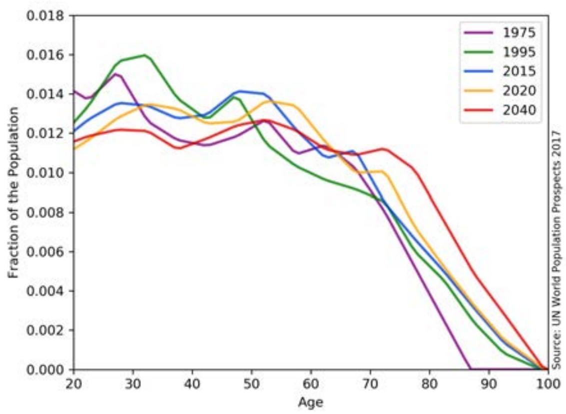
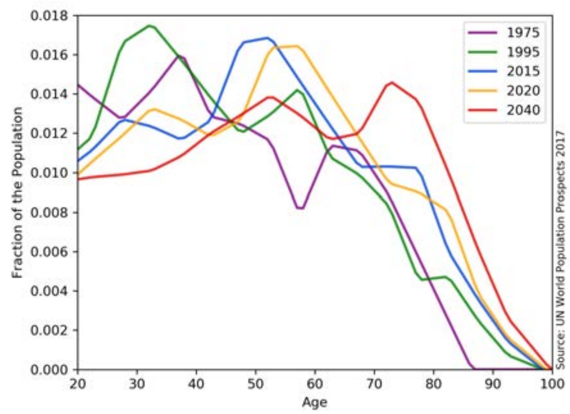


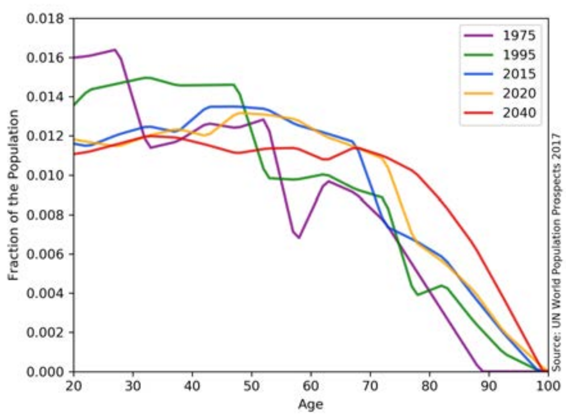
Figure 2: Life Expectancy in G7 Economies Excluding Canada and Japan



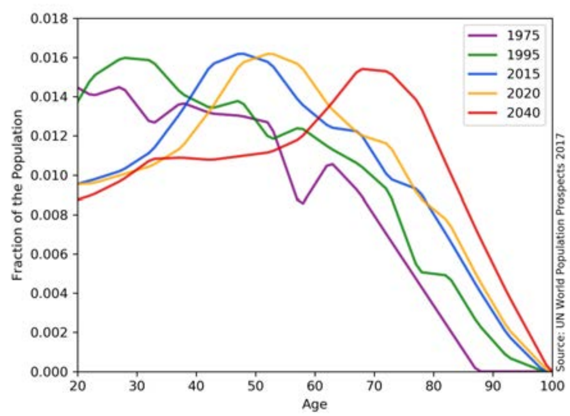
(a) United Kingdom



(b) Germany



(c) France



(d) Italy

Figure 3: Age-Cohort Distributions

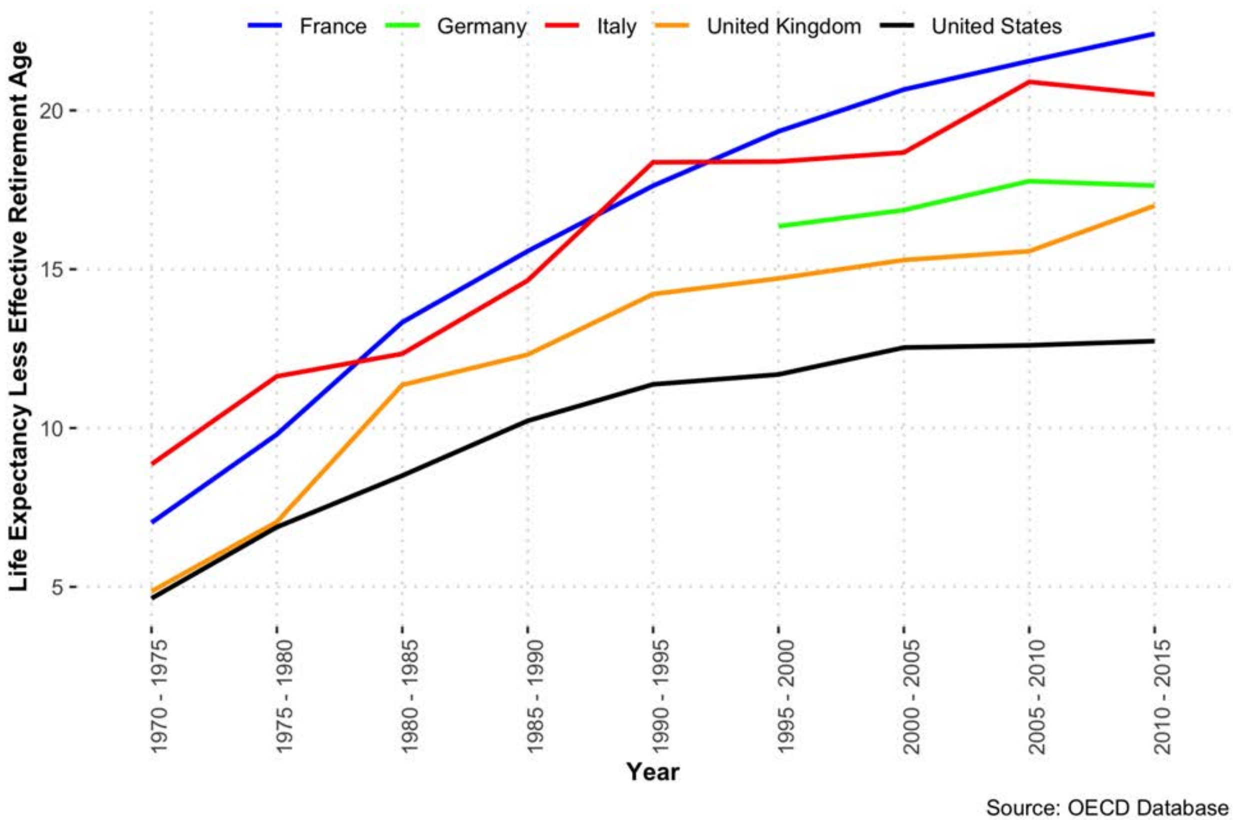
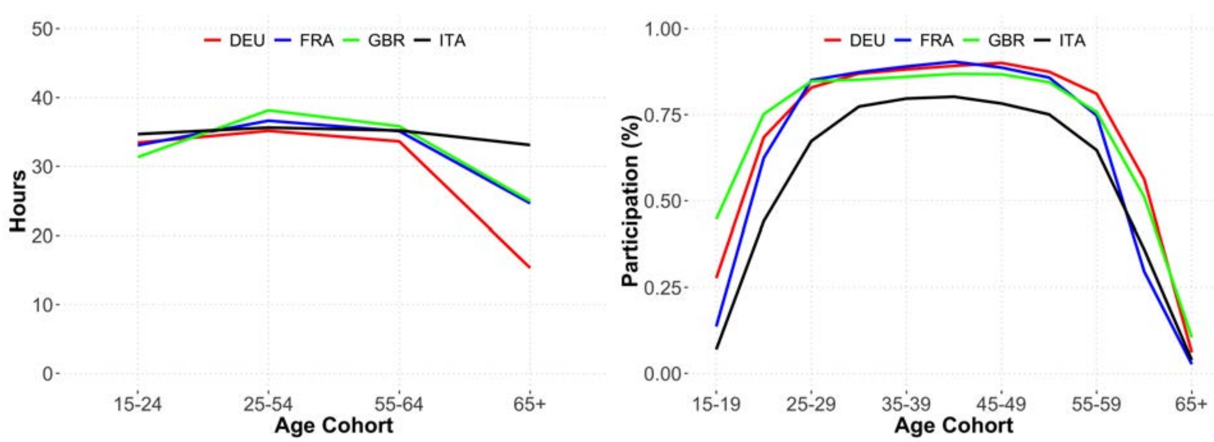


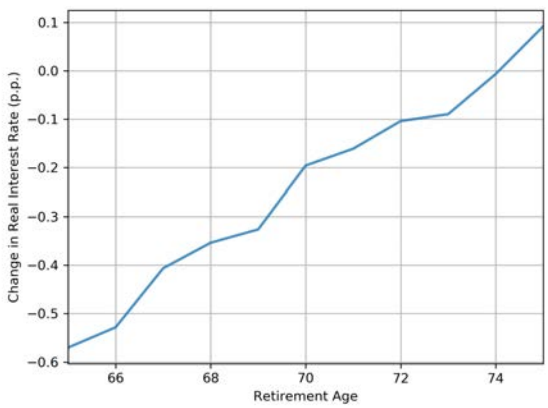
Figure 4: Years in Retirement in G7 Economies Excluding Canada and Japan



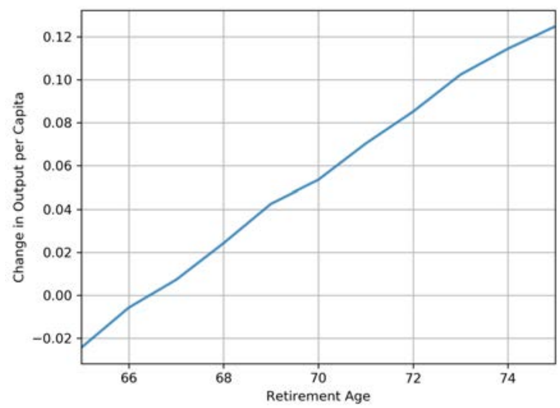
(a) Average Hours Worked

(b) Labor Force Participation

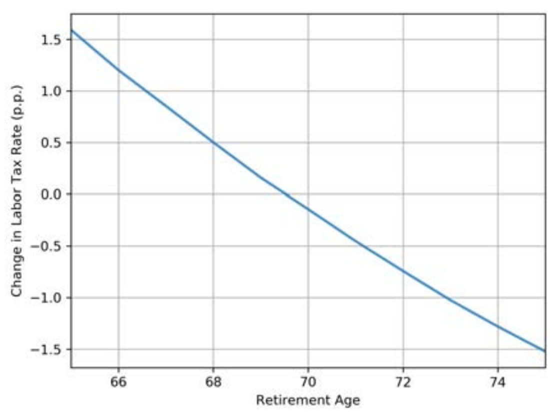
Figure 5: Life-Cycle Labor Supply in 2015



(a) Interest rate



(b) Output



(c) Tax rates

Figure 6: Sensitivity of the retirement-age assumption on key variables and predictions

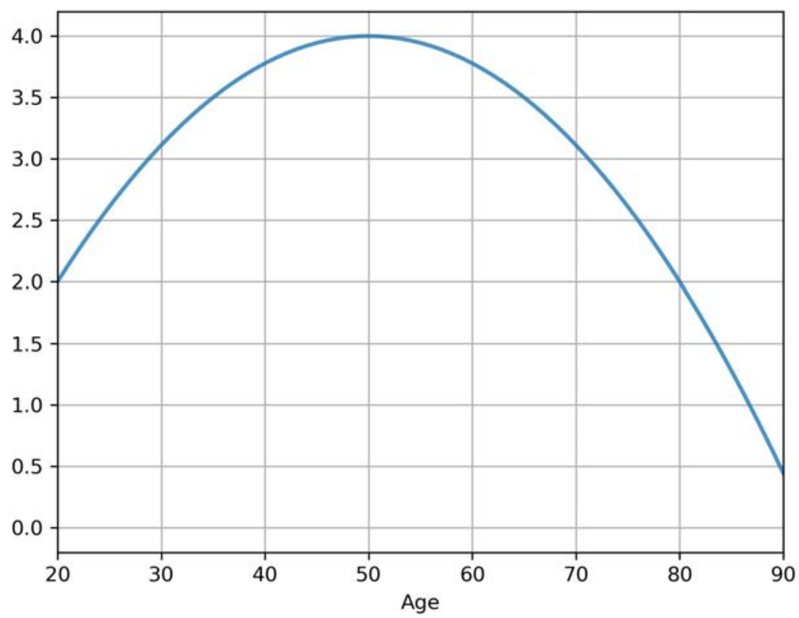


Figure 7: Life-Cycle Productivity Profile

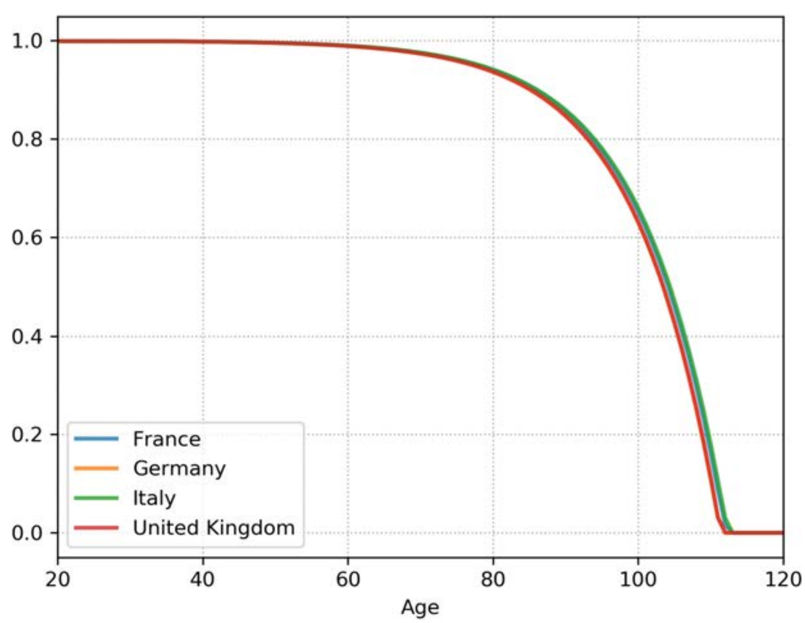


Figure 8: Conditional Survival Probability

B Tables

Table 1: Historical Growth Accounting Annualized Growth Rates

	$\gamma_{Y/pop}$	γ_A	$\alpha \cdot \gamma_{K/L}$	$\gamma_{L/pop}$	$(1-\alpha)\cdot\gamma_h$
1975-1995					
France	1.88%	1.56%	0.96%	-0.12%	-0.53%
Germany	2.30%	2.06%	0.90%	-0.09%	-0.57%
Italy	2.43%	1.41%	0.96%	0.16%	-0.09%
United Kingdom	2.26%	1.91%	0.65%	0.01%	-0.32%
United States	2.21%	1.07%	0.35%	0.77%	0.02%
1995-2014					
France	1.02%	0.65%	0.47%	0.21%	-0.30%
Germany	1.34%	0.70%	0.37%	0.65%	-0.38%
Italy	0.21%	-0.16%	0.44%	0.17%	-0.24%
United Kingdom	1.54%	0.98%	0.23%	0.44%	-0.10%
United States	1.42%	1.18%	0.52%	-0.18%	-0.11%

Table 2: Calibration Results

	$LFPR60-64$	$LFPR65-69$	$Retire.\ Age$	K/Y	$Avg.\ Hours\ Worked$
U.K.					
Data	0.37	0.110	62.0	3.02	0.34
Benchmark	0.43	0.046	61.8	3.07	0.32
Lump Sum	0.50	0.110	62.3	3.15	0.32
Labor Tax	0.50	0.110	62.3	3.02	0.32
France					
Data	0.11	0.030	59.6	3.23	0.33
Benchmark	0.28	0.033	60.0	3.27	0.29
Lump Sum	0.34	0.036	60.3	3.21	0.30
Labor Tax	0.29	0.030	59.8	3.27	0.29
Germany					
Data	0.19	0.045	60.3	3.55	0.33
Benchmark	0.38	0.065	61.1	3.65	0.28
Lump Sum	0.38	0.053	60.7	3.57	0.30
Labor Tax	0.36	0.047	60.6	3.43	0.29
Italy					
Data	0.19	0.063	59.1	4.02	0.34
Benchmark	0.28	0.050	59.7	4.16	0.29
Lump Sum	0.27	0.022	59.7	4.37	0.32
Labor Tax	0.27	0.033	59.6	4.16	0.30

Table 3: Summary of 1995 Moments by Country

Moment	**France**	**Germany**	**Italy**	**U.K.**
Labor-force participation rate for ages 60-64	11%	19%	19%	37.2%
Labor-force participation rate for ages 65-69	3.0%	4.5%	6.3%	11%
Avg. hours worked for ages 20-64	0.33	0.33	0.34	0.34
Effective retirement age	59.6	60.3	59.1	62
Real interest rate	5.75%	5.14%	6.96%	5.54%
Capital-to-output ratio	3.23	3.55	4.02	3.02
Pension outlays as a fraction of GDP	9.9%	7.4%	10.2%	7.8%

Table 4: Benchmark Model Historical Annualized Growth Summary

	1975-1995	1995-2014	Change	Percent of Slowdown
United Kingdom	0.39%	0.06%	-0.33	46%
Germany	0.60%	-0.08%	-0.68	71%
France	0.47%	-0.16%	-0.63	73%
Italy	0.57%	-0.02%	-0.59	27%

Table 5: 1975-1995 Annualized Model Growth Rates

	$\gamma_{Y/pop}$	γ_A	$\alpha \cdot \gamma_{K/L}$	$\gamma_{L/pop}$	$(1-\alpha) \cdot \gamma_h$
United Kingdom					
Benchmark	0.39	0.03	0.04	0.28	0.05
Lump Sum	0.42	0.02	0.05	0.28	0.07
Labor Tax	0.40	0.02	0.05	0.29	0.05
France					
Benchmark	0.47	0.06	0.09	0.33	-0.01
Lump Sum	0.45	0.05	0.07	0.33	0.01
Labor Tax	0.46	0.06	0.08	0.33	-0.01
Germany					
Benchmark	0.60	0.02	0.07	0.52	-0.02
Lump Sum	0.57	0.03	0.06	0.50	-0.01
Labor Tax	0.56	0.04	0.06	0.48	-0.01
Italy					
Benchmark	0.57	0.01	0.10	0.45	0.01
Lump Sum	0.57	-0.01	0.08	0.46	0.05
Labor Tax	0.51	0.01	0.06	0.43	0.02

Table 6: 1995-2015 Annualized Model Growth Rates

	$\gamma_{Y/pop}$	γ_A	$\alpha \cdot \gamma_{K/L}$	$\gamma_{L/pop}$	$(1-\alpha) \cdot \gamma_h$
United Kingdom					
Benchmark	0.06	0.03	0.08	0.03	-0.09
Lump Sum	0.06	0.03	0.07	0.03	-0.07
Labor Tax	0.01	0.05	0.04	-0.01	-0.08
France					
Benchmark	-0.16	0.04	0.09	-0.18	-0.11
Lump Sum	-0.15	0.04	0.07	-0.19	-0.07
Labor Tax	-0.24	0.06	0.05	-0.26	-0.10
Germany					
Benchmark	-0.08	0.05	0.10	-0.11	-0.12
Lump Sum	-0.11	0.04	0.07	-0.13	-0.09
Labor Tax	-0.19	0.06	0.05	-0.18	-0.12
Italy					
Benchmark	-0.02	0.12	0.15	-0.15	-0.15
Lump Sum	-0.11	0.12	0.11	-0.20	-0.14
Labor Tax	-0.18	0.14	0.09	-0.25	-0.17

Table 7: 2020-2040 Annualized Model Growth Rates

	$\gamma_{Y/pop}$	γ_A	$\alpha \cdot \gamma_{K/L}$	$\gamma_{L/pop}$	$(1-\alpha) \cdot \gamma_h$
United Kingdom					
Benchmark	-0.24	-0.01	0.05	-0.28	-0.01
Lump Sum	-0.26	-0.03	0.02	-0.28	0.04
Labor Tax	-0.35	-0.01	-0.01	-0.34	0.01
France					
Benchmark	-0.25	-0.01	0.04	-0.32	0.03
Lump Sum	-0.22	-0.03	0.04	-0.31	0.07
Labor Tax	-0.37	-0.02	-0.01	-0.38	0.04
Germany					
Benchmark	-0.52	0.02	0.08	-0.61	-0.01
Lump Sum	-0.48	-0.01	0.06	-0.59	0.06
Labor Tax	-0.71	0.01	-0.01	-0.72	0.01
Italy					
Benchmark	-0.67	-0.05	0.08	-0.76	0.05
Lump Sum	-0.64	-0.09	0.06	-0.79	0.16
Labor Tax	-1.13	-0.05	-0.07	-1.08	0.08

Table 8: Outlays as a Fraction of GDP

	U.K.	France	Germany	Italy
1975				
Lump Sum	7.10%	9.48%	7.58%	8.43%
Labor Tax	7.04%	9.44%	7.63%	8.37%
1995				
Lump Sum	7.85%	9.99%	7.39%	10.18%
Labor Tax	7.81%	9.95%	7.45%	10.24%
2015				
Lump Sum	8.81%	12.79%	10.26%	13.51%
Labor Tax	8.86%	12.95%	10.52%	13.76%
2020				
Lump Sum	9.41%	13.88%	11.05%	14.86%
Labor Tax	9.48%	14.24%	11.38%	15.31%
2040				
Lump Sum	12.51%	16.99%	16.15%	22.35%
Labor Tax	12.84%	17.93%	17.35%	24.99%

Table 9: Labor Tax Model: Projected Growth Rates for an x% Decrease in Benefits

	$\Delta\gamma_{Y/pop}$ (pp)	Δ $Retirement\ \ Age$ (yrs.)	CE (%)
UK			
5%	0.03	0.17	0.40
10%	0.07	0.43	0.80
15%	0.11	0.64	1.17
20%	0.15	0.88	1.55
France			
5%	0.09	0.46	0.63
10%	0.14	0.72	1.21
15%	0.18	1.03	1.78
20%	0.27	1.49	2.33
Germany			
5%	0.04	0.24	0.63
10%	0.13	0.59	1.32
15%	0.17	0.80	1.91
20%	0.22	1.01	2.48
Italy			
5%	0.12	0.42	1.11
10%	0.25	0.84	2.13
15%	0.37	1.29	3.11
20%	0.43	1.55	3.93

Table 10: 2020-2040 Annualized Growth Rates for a 5-Year Increase Retirement Age

	$\Delta\gamma_{Y/pop}$ (pp)	Δ $Retirement\ \ Age$ (yrs.)	CE (%)
Lump Sum			
France	0.07	0.73	1.21
Germany	0.11	0.60	1.55
Italy	0.11	0.59	2.56
United Kingdom	0.10	0.72	1.08
Labor Tax			
France	0.22	1.29	1.46
Germany	0.26	1.31	2.11
Italy	0.36	1.43	2.99
United Kingdom	0.17	1.08	1.39

Table 11: 2020-2040 Annualized Growth Rates for a 3 Year Shift in θ

	$\Delta\gamma_{Y/pop}$ (pp)	Δ $Retirement\ \ Age$ (yrs.)	CE (%)
Labor Tax			
France	0.31	1.47	2.00
Germany	0.26	1.53	2.18
Italy	0.46	1.71	2.39
United Kingdom	0.29	1.45	1.73

Table 12: Calibrated Parameters

	β	δ	χ	κ_1	κ_2	κ_3	p
U.K.							
Benchmark	0.944	0.055	0.206	0.0505	0.00181	1.414	–
Lump Sum	0.958	0.055	0.274	0.0503	0.00192	1.331	0.592
Labor Tax	0.955	0.055	0.339	0.0028	0.00225	1.285	0.583
France							
Benchmark	0.942	0.046	0.355	0.0440	0.00203	1.355	–
Lump Sum	0.953	0.046	0.392	0.0370	0.00197	1.306	0.557
Labor Tax	0.957	0.046	0.392	0.0390	0.00266	1.207	0.540
Germany							
Benchmark	0.950	0.043	0.353	0.0495	0.00224	1.310	–
Lump Sum	0.958	0.043	0.332	0.0470	0.00196	1.323	0.602
Labor Tax	0.957	0.043	0.347	0.0420	0.00294	1.196	0.578
Italy							
Benchmark	0.937	0.013	0.350	0.0495	0.00215	1.316	–
Lump Sum	0.952	0.013	0.266	0.0412	0.00232	1.304	0.723
Labor Tax	0.951	0.013	0.415	0.0014	0.00243	1.243	0.673

Table 13: Fixed Parameters

Parameter	**Source**	**France**	**Germany**	**Italy**	**U.K.**
Cohort Size	United Nations (2017)	Figure 3	Figure 3	Figure 3	Figure 3
Survival Probability	Henriksen (2015)	Figure 8	Figure 8	Figure 8	Figure 8
Life-Cycle Productivity	Hansen (1993)	Figure 7	Figure 7	Figure 7	Figure 7
Capital Share	Gollin (2002)	0.33	0.33	0.33	0.33
Utility Curvature	King et al. (1988)	1.0, 4.0	1.0, 4.0	1.0, 4.0	1.0, 4.0
Idiosyncratic Productivity	Cooley and Henriksen (2018)	0.97, 0.02	0.97, 0.02	0.97, 0.02	0.97, 0.02
Pension Eligibility Age	Blondal and Scarpetta (1997)	60	65	62	65

Table 14: Lump Sum Model: 2020-2040 Annual Growth Rates for an x% Decrease in Benefits

	$\gamma_{Y/pop}$	γ_A	$\alpha \cdot \gamma_{K/L}$	$\gamma_{L/pop}$	$(1-\alpha) \cdot \gamma_h$
UK					
5%	−0.23	−0.02	0.03	−0.27	0.03
10%	−0.21	−0.02	0.04	−0.25	0.02
15%	−0.19	−0.02	0.07	−0.24	0.01
20%	−0.17	−0.01	0.07	−0.22	−0.01
France					
5%	−0.23	−0.02	0.03	−0.30	0.06
10%	−0.21	−0.02	0.05	−0.29	0.05
15%	−0.19	−0.01	0.06	−0.28	0.03
20%	−0.17	−0.01	0.07	−0.25	0.02
Germany					
5%	−0.46	−0.01	0.07	−0.58	0.05
10%	−0.45	−0.01	0.08	−0.56	0.03
15%	−0.41	0.01	0.10	−0.55	0.02
20%	−0.39	0.01	0.11	−0.53	0.01
Italy					
5%	−0.65	−0.08	0.07	−0.78	0.14
10%	−0.64	−0.08	0.09	−0.77	0.12
15%	−0.62	−0.06	0.09	−0.77	0.11
20%	−0.59	−0.05	0.10	−0.75	0.10

Table 15: Labor Tax Model: Annualized Projected Growth Rates for an x% Decrease in Benefits

	$\gamma_{Y/pop}$	γ_A	$\alpha \cdot \gamma_{K/L}$	$\gamma_{L/pop}$	$(1-\alpha) \cdot \gamma_h$
UK					
5%	−0.32	−0.01	0.01	−0.32	0.01
10%	−0.28	−0.01	0.02	−0.29	−0.01
15%	−0.24	−0.01	0.04	−0.26	−0.01
20%	−0.20	−0.01	0.05	−0.23	−0.01
France					
5%	−0.28	−0.01	0.02	−0.32	0.03
10%	−0.23	−0.01	0.04	−0.29	0.03
15%	−0.19	−0.01	0.05	−0.25	0.02
20%	−0.10	−0.01	0.08	−0.20	0.01
Germany					
5%	−0.67	0.01	0.01	−0.69	0.01
10%	−0.58	0.01	0.04	−0.64	−0.01
15%	−0.54	0.03	0.04	−0.61	−0.01
20%	−0.49	0.02	0.07	−0.58	−0.01
Italy					
5%	−1.01	−0.05	−0.03	−1.00	0.07
10%	−0.88	−0.04	0.01	−0.93	0.07
15%	−0.76	−0.04	0.05	−0.85	0.06
20%	−0.70	−0.04	0.07	−0.80	0.06

Table 16: 2020-2040 Annualized Growth Rates for a 5 Year Increase Retirement Age

	$\gamma_{Y/pop}$	γ_A	$\alpha \cdot \gamma_{K/L}$	$\gamma_{L/pop}$	$(1-\alpha) \cdot \gamma_h$
Lump Sum					
France	−0.15	−0.02	0.06	−0.22	0.03
Germany	−0.37	0.01	0.11	−0.50	0.01
Italy	−0.54	−0.06	0.12	−0.69	0.08
United Kingdom	−0.16	−0.02	0.07	−0.20	−0.01
Labor Tax					
France	−0.15	−0.02	0.05	−0.22	0.04
Germany	−0.45	0.01	0.07	−0.53	0.01
Italy	−0.77	−0.06	0.03	−0.82	0.08
United Kingdom	−0.18	−0.02	0.05	−0.21	−0.01

Table 17: 2020-2040 Annualized Model Growth Rates for a 3 Year Shift in θ

	$\gamma_{Y/pop}$	γ_A	$\alpha \cdot \gamma_{K/L}$	$\gamma_{L/pop}$	$(1-\alpha) \cdot \gamma_h$
Labor Tax					
France	0.05	−0.01	0.08	−0.14	0.11
Germany	−0.35	0.03	0.04	−0.51	0.08
Italy	−0.67	−0.02	−0.01	−0.78	0.13
United Kingdom	−0.06	0.01	0.02	−0.17	0.08