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ENDOGENEOUS LIFE EXPECTANCY AND R&D-BASED ECONOMIC GROWTH

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Abstract

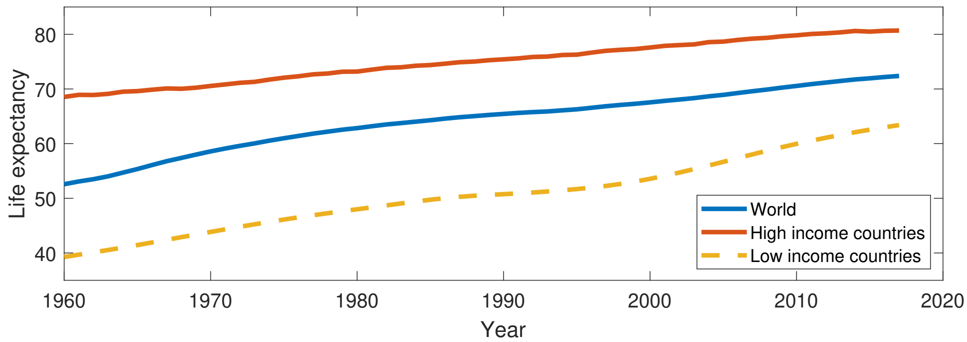
We propose an overlapping generations framework in which life expectancy is determined endogenously by governmental health investments. As a novelty, we are able to examine the feedback effects between life expectancy and R&D-driven economic growth for the transitional dynamics. We find that i) higher survival induces economic growth through higher savings and higher labor force participation; ii) longevity-induced reductions in fertility hamper economic development; iii) the positive life expectancy effects of larger savings and higher labor force participation outweigh the negative effect of a reduction in fertility, and iv) there exists a growth-maximizing size of the health care sector that might lie beyond what is observed in most countries. Altogether, the results support a rather optimistic view on the relationship between life expectancy and economic growth and contribute to the debate surrounding rising health shares and economic development.

JEL classification: I15, J11, J13, J17, O41.
Keywords: Long-run growth, horizontal innovation, increasing life expectancy, welfare effects of changing longevity, size of health-care sectors.

1 Introduction

Over the past decades, mortality has decreased at an historically unprecedented pace all over the world. As depicted in Figure 1, on a global level, life expectancy at birth has increased from 52.6 years in 1960 to 72.4 years in 2017. Nonetheless, substantial differences between different regions of the world remain. Over the same time period, the real GDP p.c. has risen roughly by a factor of 3.5 from $4,254 to $14,574 (Roser, 2019).

Figure 1: Life expectancy at birth, 1960–2017



Source: World Bank (2019)

In the literature, the following important reasons for increasing life expectancy have been proposed: medical progress, economic development, increased health shares and behavioral changes (see, for example, Christensen and Vaupel, 1996; Harper, 2014; Currie and Schwandt, 2016; Dwyer-Lindgren et al., 2017). However, the dynamic interrelations between life expectancy and economic development are less clear.

Economists have tried to shed light on the correlation and causality between health and income. The Preston curve (see Preston, 1975) provides interesting insights by highlighting the positive correlation between the development status and the health status of a country, which flattens out for high levels of income. Furthermore, as Bloom et al. (2019) show, the Preston curve has shifted upwards between 1960 and 2015 and still exhibits a strong positive correlation. All this points to a relationship between health and income that requires further investigation. In a prominent work, Acemoglu and Johnson (2007) find a negative relationship between health and economic growth by exploiting the epidemiological transition after 1940. However, this result got challenged by several contributions. Critiques by Aghion et al. (2011) and Bloom et al. (2014) mainly emphasize the role of initial health that is not considered in Acemoglu and Johnson (2007). In fact, Cervellati and Sunde (2011, 2015) show that the effect of health on economic growth hinges on a country's stage of the demographic transition. Economic growth in less developed countries with high mortality and fertility might even decrease in better health because longer lifetimes do not decrease fertility or raise educational investments. Therefore, higher survival primarily raises the population size, potentially affecting p.c. income negatively. Focusing on high income countries, the relationship between health and economic growth reverses since higher survival reduces population growth and spurs human capital investments. This negative relationship is also supported by various other works (for example Lorentzen et al., 2008; Cervellati and Sunde, 2013; Bloom et al., 2014; Hansen and Lønstrop, 2015; Gehringer and Prettner, 2019). Given the tremendous improvements in health care during large parts of the twentieth century, infant and child mortality is contributing less and less to gains in life expectancy in high income countries, leaving decreases in old-age mortality as the main engine for future increases in individual life spans (Breyer et al., 2010; Eggleston and Fuchs, 2012). Also, since health care sectors in high income countries are usually well-developed, additional gains in life expectancy come at ever higher cost, thereby raising the opportunity cost of health care, e.g. productive investments (Bhargava et al., 2001).

To analyze the complex relationship within models of economic growth, two dimensions can be distinguished – exogenous vs. endogenous life expectancy and exogenous vs. endogenous growth frameworks. There already exists quite a rich literature on exogenous life expectancy effects in both exogenous and endogenous growth models (see, for example, Blanchard, 1985; Reinhart, 1999; Heijdra and Romp, 2008; Prettner, 2013; Baldanzi et al., 2019). These models usually emphasize the saving effect, the role of human capital and the corresponding effects on productivity and provide an important basis for a better understanding of the consequences of changes in the lifetime horizon for economic growth. Nonetheless, no feedback effects on longevity can be considered, which limits the models' explanatory power. Life expectancy has been endogenized mostly in exogenous growth models as in Boucekkine et al. (2002), Chakraborty (2004) and Fanti and Gori (2014), where life expectancy increases in the public resources directed toward health or in the level of human capital. Given the endogenous nature of technological progress, these models are also limited in their explanatory power. Last, there is the category of models incorporating both endogenous survival and endogenous growth. Contributions from this category are rare. A recent paper by Kuhn and Prettner (2016) introduces individual survival into a Romer (1990) type of economy, where life expectancy increases in the health care personnel. The authors find a hump-shaped relationship between the size of the health care sector (which determines life expectancy) and economic growth. However, in their analysis they solely focus on balanced growth path effects with constant fertility and an exogenous health care sector.

To provide additional insights, we fully endogenize life expectancy similar to Chakraborty (2004) and combine it with a discrete time endogenous growth framework in the vein of Romer (1990) and Jones (1995). Old-age life expectancy increases in output per worker as well as in the health tax levied by the government. Additionally, there is a quantity-quality tradeoff in the sense that adults have to decide on the number of children to have as well as on the children's education. We include three channels through which changes in the survival probability (and vice versa) can affect economic development: the saving rate, fertility and labor force participation. Given an increase in the lifetime horizon, individuals save a larger fraction of their income to account for the prolonged retirement period (Bloom et al., 2007, 2010). To finance the increase in savings, adult consumption and fertility decrease and labor force participation increases (for works on the fertility and labor force participation effects of health see Zhang and Zhang, 2005; Angeles, 2010; Cai, 2010; García-Gómez, 2011). We show that, in principle, longer individual lifespans foster economic growth, as the positive saving and labor force participation effects outweigh the negative fertility effect. For a constant survival probability as well as for an over-sized health care sector, economic growth slows down.

The paper is organized as follows. In Section 2, we set up the model structure by implementing endogenous life expectancy into a R&D-based growth framework. In Section 3, the balanced growth path is derived analytically. In Sections 4 and 5, we calibrate the model to U.S. data and use the results to further investigate the feedback effects between life expectancy and economic growth. Finally, in Section 6, we draw conclusions and discuss potentials for future research.

2 The model

2.1 Consumption side

In the vein of Samuelson (1958) and Diamond (1965), the economy is populated by three single-sex overlapping generations: children, young adults and retirees. Childhood lasts for 20 years, adulthood for 40 years and, depending on the probability to survive to old age, ϕ_t, retirement lasts for up to 40 years.[1] Consequently, the maximum possible lifespan an individual can reach is 100 years. This is as in Baldanzi et al. (2019) with the exception that life expectancy is determined endogenously according to

$$\phi_t = \frac{b_t}{1+b_t},$$

with b_t being the health status of an adult. We closely follow Chakraborty (2004), such that b_t increases in the public resources devoted to health (see also Preston, 1975; Wolfe, 1986; Lichtenberg, 2004). The survival probability has the following properties

- $\frac{\partial \phi_t(b_t)}{\partial b_t} > 0,$
- $\lim_{b_t \to 0} \phi_t(b_t) = 0,$
- $\lim_{b_t \to \infty} \phi_t(b_t) = 1.$

There is a strictly concave non-decreasing relationship between governmental health investments and life expectancy. In the limits, if $\phi = 0$, the corresponding life expectancy equals 60 years and if $\phi = 1$, individuals reach the maximum life expectancy of 100 years with certainty.

As a simplification, all economically relevant decisions are made by the adult generation. We implicitly assume that children's consumption needs are covered for by parental consumption. Adults supply up to one unit of labor and, exactly after half of their adult period, give birth to n number of children who will become adults when their parents finish adulthood. Retirees consume out of the savings accumulated and die with certainty at the end of the period, leaving zero bequests. Maximum lifetime utility is then determined by a consumption-saving decision and by choosing the number of children, n_t, to have and the children's educational level, e_t. Consequently, individual utility is given by

$$u_t = \ln(c_{1,t}) + \phi_t \beta \ln(c_{2,t+1}) + \xi \ln(n_t) + \theta \ln(e_t), \tag{1}$$

where $c_{1,t}$ is adult consumption in period t, $c_{2,t+1}$ is old-age consumption in period $t+1$ and β, ξ, $\theta \in (0,1)$ are the utility weights of old-age consumption, fertility and

[1] Focusing on well-developed countries only, we assume that all children survive to adulthood. For interrelations between economic development, fertility and child mortality see Cigno (1998).

children's education, respectively. Individuals need to satisfy two constraints

$$\begin{aligned} (1-\psi n_t - \eta n_t e_t) w_t h_t &= c_{1,t} + s_t, & (2)\\ \frac{s_t R_{t+1}}{\phi_t} &= c_{2,t+1}. & (3) \end{aligned}$$

Equation (2) describes the economic constraint of an adult. Labor income depends on the wage rate per effective labor, w_t, on the level of individual human capital, h_t, and on the labor force participation rate, $1-\psi n_t - \eta n_t e_t$. As in Galor and Weil (2000), we assume that labor supply decreases in the fertility rate to account for the time spent raising children. Furthermore, as a simplification, we follow Prettner and Werner (2016) in assuming home education.[2] Consequently, labor force participation decreases in the time cost of raising children, ψ, in education, e_t, and in the time requirements for educating children, η. Labor income of an adult in period t can then be spent on consumption during adulthood and on savings, s_t, for retirement.

Equation (3) captures individual old-age consumption. As in standard overlapping generations frameworks, the only self-determined source of income during retirement are interest payments on the savings accumulated in the previous period. This is reflected in $s_t R_{t+1}$. To account for individuals' savings who die before reaching retirement, we follow Yaari (1965), Blanchard (1985), Chakraborty (2004) and Baldanzi et al. (2019) and implement perfect and fair annuity markets which insure individuals against the risk of dying with positive bequests before reaching the retirement stage. More specifically, at the end of adulthood, all adults invest their savings in a mutual life insurance fund. Individuals who survive to retirement receive two transfers, their deposited savings and transfers of individuals' savings who died. This is accounted for by dividing $s_t R_{t+1}$ by ϕ_t.[3] In so doing, the individual saving behavior reflects the exact anticipated life expectancy. Combining Equations (1), (2) and (3), utility maximization yields the following optimality conditions

$$\begin{aligned} c_{1,t} &= \frac{w_t h_t}{1+\xi+\beta\phi_t}, & s_t &= \frac{\beta\phi_t w_t h_t}{1+\xi+\beta\phi_t}, \\ n_t &= \frac{\xi-\theta}{\psi(1+\xi+\beta\phi_t)}, & e_t &= \frac{\theta\psi}{\eta(\xi-\theta)}. \end{aligned} \quad (4)$$

First and foremost, the wage rate per effective labor, w_t, and the level of individual

[2] To slim down the model and to put the spotlight on life expectancy effects, we abstract from baseline education that children acquire without formal schooling as in Strulik et al. (2013).

[3] Although, we do not explicitly include a pension system, the annuity dynamics are in line with Cipriani (2014) who finds a negative relationship between population aging and financial transfers received during retirement.

human capital, h_t, increase adult consumption and savings but have no direct effect on the fertility and education decisions. This is due to fertility and education being modeled in terms of time-opportunity cost rather than in terms of absolute cost. There is an income-independent quantity-quality tradeoff, which is reflected in the optimality conditions for n_t and e_t. While the preferences for children, ξ, raise fertility, they decrease educational efforts. The reverse holds true for the preferences for education, θ. For the reminder of the paper, $\xi > \theta$ is assumed to rule out negative fertility rates.

The effects of the survival probability, ϕ_t, are similar to the ones of the individual discount factor, β. A change in life expectancy induces the same individual behavior – the higher the probability to survive to old age, the less individuals discount utility derived from future consumption. Therefore, both β and ϕ_t increase savings and decrease consumption of adults. Also, fertility decreases in β and ϕ_t since a higher preference for future consumption decreases the willingness of adults to free resources for children These relationships are well-known from previous works (Blackburn and Cipriani, 2002; Zhang and Zhang, 2005; Chen, 2010). However, since our survival probability is endogenous, its marginal effects change as the economy is growing. Therefore, the incentives to save and to have children change over time, which, in turn, affects research and production. Given that capital accumulation, population growth and technological progress are fundamental drivers of economic development (Ramsey, 1928; Solow, 1956; Cass, 1965; Koopmans, 1965; Romer, 1990), implementing an endogenous life expectancy improves our understanding of economic growth processes.

Inspecting the fertility rate more closely, we observe that it is constant in the long run if the economy experiences sustained economic growth.

$$n_t = \begin{cases} \frac{\xi-\theta}{\psi(1+\xi+\beta)} & \text{for } \lim_{b_t\to\infty} \phi_t\left(b_t\right) = 1, \\ \frac{\xi-\theta}{\psi(1+\xi+\beta\phi_t)} & \text{otherwise.} \end{cases}$$

The same framework without lifetime uncertainty would yield a constant fertility rate from the beginning on. The effect of economic development on fertility would be abrogated which can be reasonable if focusing solely on advanced economies that have exhibited low and relatively constant fertility rates over the last few decades (Prettner and Werner, 2016). By introducing an endogenously determined life expectancy, it is possible to separate the longevity effect on fertility decisions from the income effect on fertility decisions, which leads us to Remark 1.

Remark 1. *Increases in life expectancy induce higher savings for retirement at the* *expense of reduced fertility.*

These relationships are in line with the literature surrounding longevity and economic growth (see Blackburn and Cipriani, 2002; Zhang and Zhang, 2005; Cervellati and Sunde, 2005). Given that children born in period t become adults in period $t+1$, the size of the labor force, L_t, evolves according to

$$L_{t+1} = \frac{\xi - \theta}{\psi(1 + \xi + \beta\phi_t)} L_t.$$

Again, for sustained economic growth, life expectancy will be at its upper limit such that population growth is constant in the long run. Turning towards human capital creation, the law of motion for individual human capital is given by

$$h_{t+1} = A_E e_t h_t.$$

Since home education is assumed, parents' level of human capital, h_t, the educational effort, e_t, and parents' productivity in education, A_E, determine the level of individual human capital of the next generation. Economy-wide aggregate human capital is then given by

$$H_t = h_t L_t, \tag{5}$$

and the labor force participation rate can be expressed as

$$\Omega_t = \frac{1 + \beta\phi_t}{1 + \xi + \beta\phi_t}. \tag{6}$$

Combining Equations (5) and (6), the stock of aggregate human capital available for production and R&D, $\tilde{H}_t$, can be calculated as

$$\tilde{H}_t = \Omega_t H_t. \tag{7}$$

The available stock of aggregate human capital determines overall labor input. Since the labor force participation rate increases but fertility decreases in life expectancy, the long-run effect is ambiguous and requires further investigation. We go into more details in Sections 4 and 5.

2.2 Government

Similar to Barro (1990), the government finances its health spending by taxing aggregate income, Y_t^{agg}, with a health tax, τ. It needs to keep a balanced budget at all times, i.e., health investments can only be financed by the tax income received in the same period. The governmental constraint then reads

$$\tau Y_t^{agg} = B_t,$$

where the left-hand side are aggregate governmental revenues and the right-hand side is aggregate governmental health spending, B_t. Incorporating a medical technology, λ, and remembering that the government only aims at improving adults' health, the health status of an adult is given by

$$b_t = \lambda \frac{B_t}{L_t}.$$

Individuals' health and, with it, the probability to survive to retirement increases in the medical resources per adult invested and in the productivity of these investments.

2.3 Production side

The production side of the economy builds up on Romer (1990), Jones (1995) and Prettner and Werner (2016). There are three sectors: the final goods sector, the intermediate goods sector and the R&D sector. In short, employing scientists, new ideas/blueprints are developed in the perfectly competitive R&D sector and are sold to an intermediate goods producer who then becomes the monopolist in producing that specific product for one period. The intermediate good of variant i, x_t^i, is produced in a one-for-one technology using physical capital, k_t, as the only input. Due to Dixit and Stiglitz (1977) monopolistic competition, the intermediate good is sold with a mark-up over the market price to the final goods producer. The operating profits are necessary to compensate for R&D expenses.[4] The final goods producer uses the intermediate good as well as final goods workers as inputs to produce the final good under perfect competition.

Life expectancy affects productivity and production through two channels: aggregate savings, $S_t = s_t L_t$, and the available aggregate human capital, $\tilde{H}_t$. Longevity-induced changes in the saving behavior affect the capital that can be invested in intermediate goods companies, which, in turn, affects the production of new blueprints and final goods production. The size of the labor force and with it also R&D and final goods production, is affected twofold: on the one hand, through fertility, increases in life expectancy reduce the future size of the workforce, on the other hand,

[4]The monopolist only owns the patent for one period. For all future periods, we assume that the government sells the patent and invests the proceeds unproductively.

fewer children increase labor force participation.

The final good, Y_t, is produced according to

$$Y_t = (1-\tau)\left(H_t^Y\right)^{1-\alpha}\sum_{i=1}^{A_t}\left(x_t^i\right)^\alpha,$$

where H_t^Y denotes workers employed in final goods production, A_t is the number of differentiated blueprints developed until time t, x_t^i is the number of machines for each blueprint i used in final goods production and α is the elasticity of final output with respect to machines. We include $(1-\tau)$ to account for the governmental health tax.[5] Perfect competition ensures that all production factors are paid their marginal value products, such that the wage per effective worker, w_t^Y, and the price for machines of type i, p_t^i, are given by, respectively

$$w_t^Y = \frac{\partial Y_t}{\partial H_t^Y} = (1-\alpha)(1-\tau)\left(H_t^Y\right)^{-\alpha}\sum_{i=1}^{A_t}\left(x_t^i\right)^\alpha, \tag{8}$$

$$p_t^{Y,i} = \frac{\partial Y_t}{\partial x_t^i} = \alpha(1-\tau)\left(H_t^Y\right)^{1-\alpha}\left(x_t^i\right)^{\alpha-1}. \tag{9}$$

Turning to the monopolistic intermediate goods sector, the profit function of intermediate goods producer i, $\pi_t^{x,i}$, reads

$$\pi_t^{x,i} = p_t^{Y,i}x_t^i - R_t x_t^i. \tag{10}$$

Combining Equations (9) and (10) and using $k_t^i = x_t^i$, profit maximization results in

$$\frac{\partial \pi_t^{x,i}}{\partial k_t^i} = 0 \qquad \Leftrightarrow \qquad p_t^i = \frac{R_t}{\alpha}. \tag{11}$$

The more differentiated the intermediate goods are, i.e., the smaller α is, the more market power the monopolist has and the higher the mark-up over the market price is. Since all monopolists are similar, we can infer from Equation (11) that all monopolists charge the same price and produce the same amount, i.e., $p_t^i = p_t$ and $x_t^i = x_t$. Therefore, dropping the machine variety index i, the aggregate production function can be written as

$$Y_t = (1-\tau)\left(A_t H_t^Y\right)^{1-\alpha} K_t^\alpha,$$

[5] This formulation corresponds to the government taxing capital and labor income at equal rates.

where $K_t = A_t k_t$ is aggregate capital. The production function has now the same Cobb-Douglas form as in standard neoclassical growth models (see, for example, Solow, 1956).

Moving on to the R&D sector, new ideas are developed according to the following knowledge production function

$$A_{t+1} - A_t \;=\; \delta A_t^{\chi} H_t^A. \tag{12}$$

H_t^A are scientists employed in R&D. Their productivity depends on the general productivity in research, δ, and on the number of already existing ideas (standing on shoulders effect). We allow for intertemporal knowledge spillovers $\chi \in (0,1)$ to partly nest the Jones (1995) framework. Given the price of a patent, p_t^A, and the wage rate per effective labor of scientists, w_t^A, the profit function in the R&D sector is given by

$$\pi_t^A \;=\; p_t^A \delta A_t^{\chi} H_t^A - w_t^A H_t^A.$$

Perfect competition then allows to derive an expression for w_t^A.

$$\frac{\partial \pi_t^A}{\partial H_t^A} = 0 \qquad \Leftrightarrow \qquad w_t^A = p_t^A \delta A_t^{\chi}. \tag{13}$$

The wage per effective labor of scientists depends on the price that can be charged for one blueprint and on scientists' overall productivity.

2.4 Market clearing

The first condition for an equilibrium is that operating profits of the intermediate goods producer, π_t^x, and the price of a patent, p_t^A, equal. Combining Equations (9), (10) and (11), we observe that this relationship holds for

$$p_t^A = \pi_t^x = \alpha(1-\alpha)\frac{Y_t}{A_t}. \tag{14}$$

The second condition for an equilibrium is that wages of workers and scientists equal, $w_t^Y = w_t^A = w_t$. Equating Equations (8) and (13) and using Equation (14), we derive an equilibrium condition for aggregate human capital employed in final goods production

$$H_t^Y \;=\; \frac{A_t^{1-\chi}}{\delta\alpha}. \tag{15}$$

Considering that human capital is solely employed in final goods production and in R&D, H_t^A is given as

$$H_t^A = \tilde{H}_t - H_t^Y. \tag{16}$$

Inserting Equations (7) and (15) into Equation (16), we are able to derive an expression for aggregate human capital employed in R&D

$$H_t^A = \Omega_t H_t - \frac{A_t^{1-\chi}}{\delta\alpha}. \tag{17}$$

Using Equation (17) in the knowledge production function, the equilibrium stock of ideas evolves according to

$$A_{t+1} = \delta A_t^{\chi} \Omega_t H_t - A_t \left(\frac{1-\alpha}{\alpha}\right). \tag{18}$$

Defining a growth rate as $g_{x,t} = (x_{t+1} - x_t)/x_t$, the growth rate of new ideas, $g_{A,t}$, is given by

$$g_{A,t} = \delta A_t^{\chi-1} \Omega_t H_t - \frac{1}{\alpha}. \tag{19}$$

Since we are interested in the growth effects of changes in life expectancy, we inspect Equation (19) with respect to ϕ_t. We observe that the survival probability enters through the labor force participation rate, Ω_t, which leads us to the following remark.

Remark 2. *In the short run, through higher labor force participation, higher life expectancy increases the rate at which new ideas are developed.*

Proof. The partial derivative of $g_{A,t}$ with respect to the survival probability, ϕ_t, is given by

$$\frac{\partial g_{A,t}}{\partial \phi_t} = \delta A_t^{\chi-1} H_t \frac{\beta\xi}{(1+\xi+\beta\phi_t)^2}.$$

The denominator of this expression is always positive. For $\delta, \beta, \xi \in (0,1)$ and for the reasonable case of $A_t > 0$ and $H_t > 0$, the numerator is also positive, such that the survival probability has a strictly positive effect on productivity growth in the short run. □

Last, capital accumulation needs to be derived. For full depreciation of physical capital and since savings of period t are invested in period $t+1$, the standard law of motion for capital can be applied, where aggregate savings determine the stock of aggregate physical capital in the next period

$$K_{t+1} = s_t L_t.$$

Combining Equations (8) and (15), the wage rate per effective labor can be written as

$$w_t = (1-\alpha)(1-\tau)A_t^{1-\alpha}K_t^{\alpha}\left(\frac{A_t^{1-\chi}}{\delta\alpha}\right)^{-\alpha}.$$

Together with the expression for individual savings, s_t, from Equation (4), the stock of physical capital then evolves according to

$$K_{t+1} = L_t h_t \frac{\beta\phi_t}{1+\xi+\beta\phi_t}(1-\alpha)(1-\tau)A_t^{1-\alpha}K_t^{\alpha}\left(\frac{A_t^{1-\chi}}{\delta\alpha}\right)^{-\alpha}.$$

The survival probability, ϕ_t, enters positively through the propensity to save, $(1+\beta\phi_t)/(1+\xi+\beta\phi_t)$. Economic progress that raises life expectancy entails a multiplying effect, since a longer life span increases capital accumulation and, with it, economic progress and life expectancy.

To sum up, for labor market and financial market clearing, we have the following system of equations that describes how our model economy evolves over time

$$\begin{aligned}
A_{t+1} &= \delta A_t^{\chi}\frac{1+\beta\phi_t}{1+\xi+\beta\phi_t}h_t L_t - A_t\frac{1-\alpha}{\alpha}, \\
K_{t+1} &= L_t h_t \frac{\beta\phi_t}{1+\xi+\beta\phi_t}(1-\alpha)(1-\tau)A_t^{1-\alpha}K_t^{\alpha}\left(\frac{A_t^{1-\chi}}{\delta\alpha}\right)^{-\alpha}, \\
Y_{t+1}^{Agg} &= \left(\frac{A_{t+1}^{2-\chi}}{\delta\alpha}\right)^{1-\alpha}K_{t+1}^{\alpha}, \\
L_{t+1} &= L_t\frac{\xi-\theta}{\psi(1+\xi+\beta\phi_t)}, \\
h_{t+1} &= \frac{A_E\theta\psi}{\eta(\xi-\theta)}h_t, \\
\phi_{t+1} &= \frac{\lambda\tau\frac{Y_{t+1}^{Agg}}{L_{t+1}}}{1+\lambda\tau\frac{Y_{t+1}^{Agg}}{L_{t+1}}}.
\end{aligned}$$

For a given set of parameters and by choosing initial values for the endogenous variables A_0, K_0, L_0 and h_0, this system fully describes the evolution of our model economy over time. Life expectancy, represented by the survival probability ϕ_{t+1}, is, of course, also endogenous but is completely determined inside the model.

3 Balanced growth path

The system above can be solved analytically by deriving its balanced growth path (BGP). Along the BGP, $g_{x,t} = g_{x,t+1} = g_x$ must hold. In the limit, the survival probability approaches

$$\lim_{y_t \to \infty} \phi_t(y_t) = 1,$$

such that we can drop it in the BGP analysis. Accordingly, fertility is constant and the growth rate of the labor force is given by

$$g_L = \frac{L_{t+1}}{L_t} - 1 = \frac{\xi - \theta}{\psi(1+\xi+\beta)} - 1.$$

The growth rate of individual human capital is also constant and given by

$$g_h = \frac{h_{t+1}}{h_t} - 1 = A_E \frac{\theta\psi}{\eta(\xi-\theta)} - 1.$$

For a constant labor force participation rate, the growth rate of new ideas can be derived as

$$g_{A,t} = \frac{A_{t+1}}{A_t} - 1 = \delta A_t^{\chi-1} \frac{1+\beta}{1+\xi+\beta} h_t L_t - \frac{1}{\alpha}.$$

Setting $g_{A,t} = g_{A,t+1}$ and solving for g_A, the BGP expression reads

$$g_A = \left[\frac{A_E\theta}{\eta(1+\xi+\beta)}\right]^{\frac{1}{1-\chi}} - 1,$$

where the term in square brackets represents the growth factor of aggregate human capital. The BGP expressions for physical capital and for aggregate production can be derived in the same way and read

$$g_K = \left[\frac{A_E\theta}{\eta(1+\xi+\beta)}\right]^{\frac{2-\chi}{1-\chi}} - 1,$$
$$g_{Y^{agg}} = \left[\frac{A_E\theta}{\eta(1+\xi+\beta)}\right]^{\frac{2-\chi}{1-\chi}} - 1,$$

where we note that $g_K = g_{Y^{agg}}$. Since there are no life expectancy effects in the long run, which seems reasonable considering that life expectancy gains are slowing down (see Olshansky et al., 2005; Dong et al., 2016), economic progress is solely driven by growth in aggregate human capital and in the intertemporal knowledge spillovers.

This result is similar to Prettner and Werner (2016). We summarize this is in the following proposition.

Proposition 1. *As the economy progresses, life expectancy reaches an upper limit, such that there are no more longevity-induced growth effects in the long run.*

This proposition has to be treated with some caution. From an analytical perspective, setting $\phi = 1$ in the long run is correct, however, it ignores level effects and, most importantly, it ignores that life expectancy is still projected to further increase over the next decades (Oeppen et al., 2002; Strulik and Vollmer, 2013; Kontis et al., 2017). To account for that, we examine the transitional dynamics in Sections 4 and 5.

4 Simulation

To analyze the transitional dynamics and to discuss the plausibility of our results, we compare the model dynamics to U.S. data over the period 1960–2017. Given the scope of the paper, we aim at resembling developments in p.c. GDP, life expectancy at birth, fertility and the population size. All data have been taken from the World Bank (2019).

The parameter and initial values chosen are summarized in Table 1. The health tax rate is set to 11.4%, which corresponds to the average U.S. national health expenditure as percentage of GDP over the chosen time horizon (CMS.gov, 2019). The discount factor of $\beta = 0.67$ implies an annual discount rate of 2%, which is in line with Auerbach and Kotlikoff (1987). The value of the elasticity of final output with respect to intermediate inputs, α, is set to 0.3, which is close to the standard value used in the literature (Jones, 1995; Acemoglu, 2009). Also, $\psi = 0.08$ is similar to Strulik et al. (2013). All other values are chosen for the model to fit the U.S. data as precisely as possible.

To ensure sure that the model resembles the economic development of the U.S. reasonably well, Figures 2 and 3 show to the evolution of p.c. output and of the population size in the data (dashed red line) and in the model (solid blue line). Keeping in mind that the model economy consists of three overlapping generations, the model population size needs to be derived first. We do so by calculating the size of the entire population in period t as $Pop_t = \phi_{t-1}L_{t-1} + L_t + 0.5n_tL_t$, where the first term refers to retirees, the second term are adults and the third term represents children. The model p.c. GDP is then calculated by dividing aggregate output by the population size, i.e., $y_t = Y_t^{agg}/Pop_t$. We observe that p.c. GDP in the data

Table 1: Parameter and initial values for the simulation

Parameter	Value	Parameter	Value	Variable	Value
τ	0.114	α	0.3	A_0	17.5
β	0.67	δ	6.5	K_0	0.8
ψ	0.08	χ	0.076	L_0	10
ξ	0.327	A_E	1.65	h_0	1
θ	0.181	η	0.16		
λ	0.9				

and in the model increase over time by a factor of three, approximately. In the data, p.c. GDP growth accelerates in the 1980's and 1990's and partially slows down afterwards. In the model, a similar trend is visible. Economic progress is strong until around the year 2000 when the dot-com bubble burst and slows down afterwards. Also, the increase in the size of the population matches the one in the U.S.

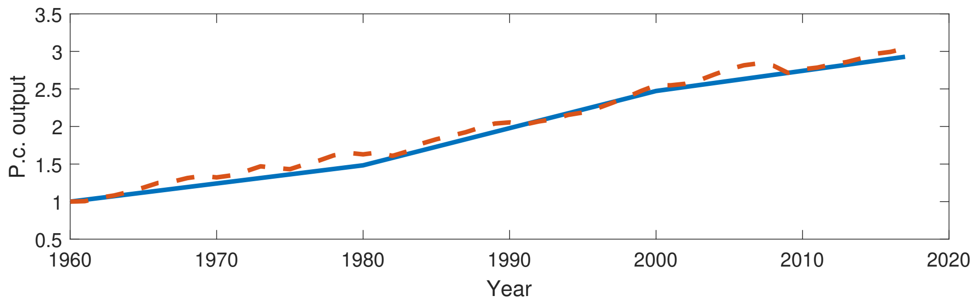


Figure 2: Evolution of p.c. output (model prediction: solid blue line; data: dashed red line)

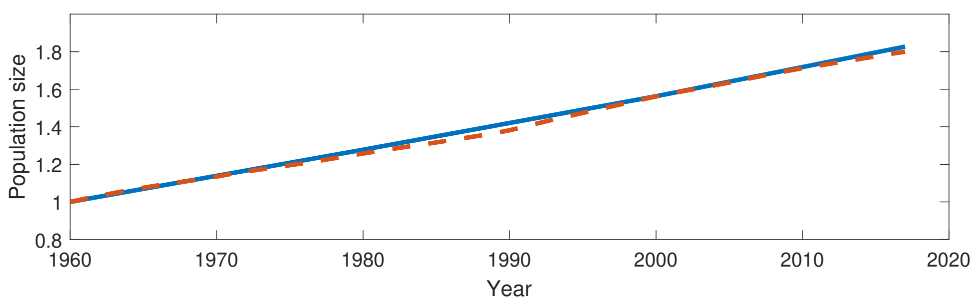


Figure 3: Evolution of the population size (model prediction: solid blue line; data: dashed red line)

Turning to the underlying driving forces of economic growth, changes in life expectancy are of the main interest. U.S. life expectancy has been rising by approximately nine years from 1960–2010 and is stagnant since then. In Figure 4, the model life expectancy resembles the data quite well, only underestimating the slowdown during the last decade. A critical examination, however, calls for caution. The stagnant U.S. life expectancy is not driven by stagnant economic development (as the model would suggest) but by several other aspects such as increased rates of deaths of despair and unequal access to health services (Case and Deaton, 2015; Dowell et al., 2017; Harper et al., 2017) that are out of the scope of this paper. Given the positive effect of life expectancy on economic growth, discussed in Section 5, and also supported by other studies (Lorentzen et al., 2008; Cervellati and Sunde, 2013; Bloom et al., 2014), this result should rather be an incentive for governments to improve health services in order to not only decrease mortality but to also promote long-run growth. This conclusion is consistent with Baldanzi et al. (2019) where increases in life expectancy increase both productivity and individual utility derived from living longer. We further elaborate on that in the next section.

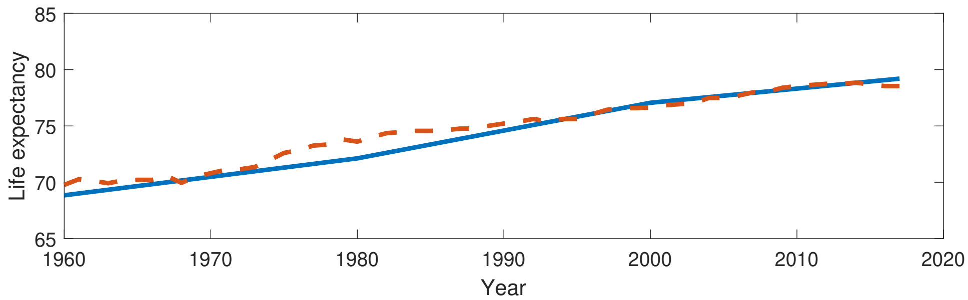


Figure 4: Evolution of life expectancy (model prediction: solid blue line; data: dashed red line)

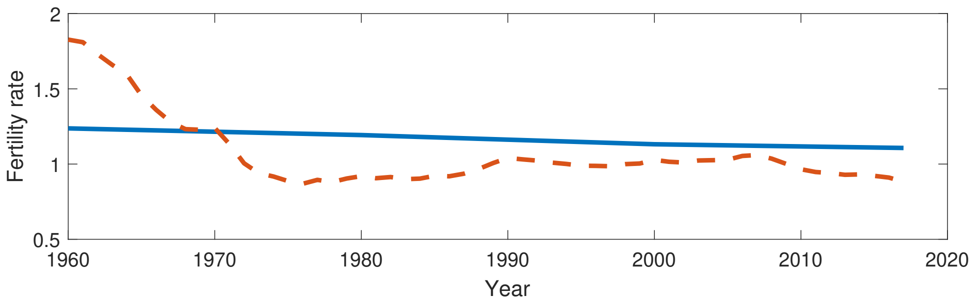


Figure 5: Evolution of fertility (model prediction: solid blue line; data: dashed red line)

Figure 5 visualizes the fertility effects of changes in the lifetime horizon. Fertility data are transformed into the number of unisex adults to make them comparable to the model results. In the data, there is a sharp decrease in fertility until the mid 1970's visible. Afterwards, fertility fluctuates just below the replacement level. Obviously, in the model, the longevity-induced fertility decline is not able to explain the sharp decrease we see in the data. However, the life expectancy effect becomes visible. For the chosen parameter values, over time, the model fertility rate declines to 0.91 along the BGP and approaches the fertility rate that we observe in the data. Remembering that the change in the model fertility is solely driven by changes in life expectancy, there is another possible takeaway. The unisex U.S. fertility rate has fallen by 0.95, while the model fertility rate has fallen by 0.13. Accordingly, the model captures approximately 14% of the changes in fertility over that time horizon, which leads us to Remark 3.

Remark 3. *The model result suggests that over the period 1960–2017, 14% of the observed decline in the U.S. fertility rate is due to increases in life expectancy.*

This result can be explained as follows. The quantity-quality tradeoff initiated through increases in income is usually assumed to be the main driver for reductions in fertility (Becker and Lewis, 1973). Through the design of our model economy, this tradeoff is non-existent over time and the only time-dependent effect remaining is how a change in the lifetime horizon affects individual choices. In our case, as life expectancy increases, individuals require higher savings for old-age consumption. In a standard overlapping generations setting, reduced adult consumption would be the only effect. In our setting, individuals additionally have the opportunity to increase their lifetime earnings by working more, i.e., by increasing the labor force participation rate. Therefore, they choose to have fewer children in order to increase labor income. Although, this is typically not the main motivation for having fewer children, it is one piece of the puzzle to explain fertility behavior and its economic implications.

5 Comparative statics

To shed some light on the directions and the magnitudes of the described channels, we test how p.c. output in the calibrated model changes if life expectancy is kept completely constant, respectively, if only single channels are switched off. As displayed in Figure 6, in the baseline case with a fully endogenous survival probability, p.c. output increases by a factor of 2.93. To asses the overall effect, we keep the economy-wide life expectancy in 1960 constant and observe a reduction in p.c. output of 11.9% over 58 years. This result comes as expected and is in line with the central conclusions of many other works (see, for example, Chakraborty, 2004; Cervellati and Sunde, 2011; Prettner, 2013; Prettner and Trimborn, 2017). Without any longevity-induced effects over time, there is less innovation and less capital, which drags down growth in the economy.

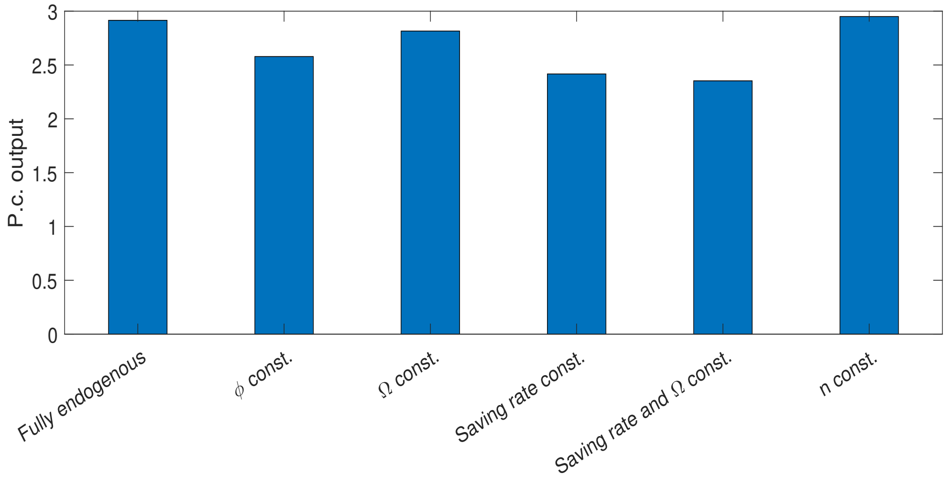


Figure 6: Level of p.c. output keeping different channels constant

In a second step, we are interested in disentangling the aggregate life expectancy effect. We do so by keeping the survival probability in savings, labor force participation and fertility constant, separately and sequentially. First of all, we notice that all channels point in the expected directions. As life expectancy is switched off in labor force participation, p.c. output decreases to 2.82. The effect is even stronger for savings, where p.c. output in 2017 would only be at 2.42 times the level in 1960. Combining both channels, the reduction in p.c. output amounts to 0.57 or 19.5% in total. For fertility, the opposite effect can be observed. Ignoring the effect of changes in longevity on the fertility decision, p.c. output increases by 0.008 because of a larger workforce, which translates into a higher growth rate of new ideas. This change seems reasonably small considering that only longevity-induced changes in fertility are being accounted for. We summarize the findings of this comparative static exercise in the following remark.

Remark 4. *Through capital accumulation and the larger number of scientists and workers, life expectancy induces economic growth. The positive effects of higher savings and higher labor force participation outweigh the negative one of lower fertility.*

In principal, there are further potential effects that could be considered in future works. Just to mention a few, including doctors and nurses as a third type of human capital would impose an additional negative effect of life expectancy on economic development since longer lives would reduce the share of human capital available for production and R&D. One potential positive effect that has been abstracted from in this analysis is the income-dependent quantity-quality tradeoff. Incorporating longevity- or income-determined education as in de la Croix and Licandro (1999) and

Strulik et al. (2013) would weaken the negative fertility effects and could, potentially, even outweigh them.

So far, the average U.S. health share of 11.4% between 1960–2017 has been used in the analysis. To gain additional insights into the relationship between life expectancy and economic development, in Figure 7 we investigate the maximum attainable 2017 life expectancy and level of p.c. output for $\tau \in [0, 1]$.

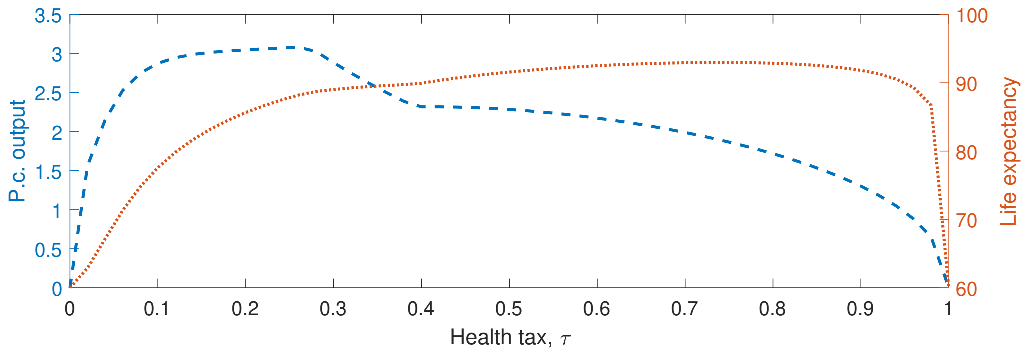


Figure 7: p.c. output and life expectancy for $\tau \in [0, 1]$ (p.c. output: dashed blue line; life expectancy: dotted red line)

As expected, we find a hump-shaped relationship. Also, for $\tau = 0$ and $\tau = 1$ zero production takes place. For zero health investments, the survival probability and the saving rate are zero and, thus, the capital stock and production are zero, too. For small health shares, the gains in output as well as in life expectancy are large. According to our model, a maximum output of $y^{max} = 3.08$ can be reached with a tax rate of $\tau = 0.271$. This corresponds to a life expectancy of 88.6 years. For larger health shares, there is a steep decline in output. The logic behind is that, at some point, the positive effects of increasing longevity are outweighed by the resource demand of health care. Interestingly, life expectancy continues to increase way beyond the growth maximizing tax rate. For $\tau = 0.734$, a maximum life expectancy of 92.9 years can be reached. The tradeoff in terms of economic development is, however, huge. Compared to the growth-maximizing size of the health care sector, an additional 3.85 years of life expectancy come at the cost of reducing p.c. output by 38.2%.

Remark 5. *Increasing the health share beyond its growth-maximizing size comes at the cost of a steep decline in p.c. output, while the additional gains in life expectancy are rather small.*

Our results also contribute to the discussion surrounding rising health shares and the consequent effects on economic development. Given that the average OECD health share has increased from 9.3% to 12.6% over the period 2000–2017 (World Bank, 2019), we can, at least, be guardedly optimistic that this increase in absolute and relative health expenditures did not only extend individual's lives but also fostered economic growth. This result contrasts Kuhn and Prettner (2016) who include health care personnel and find a smaller optimal size of the health sector of 8.61% along the BGP. Since in our framework, the optimal health share decreases over time and remembering that we abstract from human capital employed in health care, a larger optimal size of the health sector is corollary.

Turning to the welfare effects of longevity-driven economic growth, Kuhn and Prettner (2016) conduct an analysis on the tradeoff between life and growth and find that it can be optimal to increase the size of the health care sector beyond its growth growth-maximizing size. In principle, our results do not rule out this conclusion, nonetheless, a thorough analysis including more generations would be necessary to properly assess the welfare effects within our framework.

6 Conclusions

We introduce an endogenous survival probability into a growth framework driven by purposeful R&D. The frequency at which new ideas are developed increases in the level of aggregate savings and in the number of scientists employed. Higher savings imply higher operating profits since more machines can be produced. This raises the demand for and, thus, the wage rate of scientists, resulting in higher R&D employment and faster economic progress.

Life expectancy increases in the public resources devoted toward health, which, in turn, raises the incentives to save and to work more, while it induces a negative effect on the fertility decision. We disentangle the separate channels and are able to show that, overall, life expectancy exerts positive growth effects. The reduction in the size of the labor force over time is overcompensated by higher labor force participation and, especially, by higher savings and investments. Additionally, we show that the growth-maximizing size of the health care sector is way smaller than the size that would maximize life expectancy. Given that within the OECD, the average share of the health care sector is substantially smaller than our growth-maximizing size, devoting further resources toward health care might not only increase life expectancy but also foster economic development.

Our model approach allows for several interesting extensions. We abrogate from income-dependent education, which would, most likely, spur longevity-induced growth effects. Also, including human capital employed in health care might provide additional interesting insights, as increases in life expectancy would draw away labor from production and R&D and exert a potential negative effect on economic growth. Related to that, dividing the health sector into health care personnel and medical researchers could be a promising avenue for future research because it would allow for a more realistic modeling of aging.

References

Acemoglu, D. (2009). *Introduction to Modern Economic Growth.* Princeton University Press, Princeton, NJ, USA.

Acemoglu, D. and Johnson, S. (2007). Disease and Development: The Effect of Life Expectancy on Economic Growth. *Journal of Political Economy*, Vol. 115(No. 6):925–985.

Aghion, P., Howitt, P., and Murtin, F. (2011). The Relationship Between Health and Growth: When Lucas Meets Nelson-Phelps. *Review of Economics and Institutions*, Vol. 2(No. 1):1–24.

Angeles, L. (2010). Demographic transitions: analyzing the effects of mortality on fertility. *Journal of Population Economics*, Vol. 23(No. 1):99–120.

Auerbach, A. J. and Kotlikoff, L. J. (1987). *Dynamic Fiscal Policy.* Cambridge University Press.

Baldanzi, A., Prettner, K., and Tscheuschner, P. (2019). Longevity-induced vertical innovation and the tradeoff between life and growth. *Journal of Population Economics*, Vol. 32(No. 4):1293–1313.

Barro, R. J. (1990). Government spending in a simple model of endogeneous growth. *Journal of Political Economy*, Vol. 98(No. 5):103–125.

Becker, G. S. and Lewis, H. G. (1973). On the interaction between the quantity and quality of children. *Journal of Political Economy*, Vol. 81:279–288.

Bhargava, A., Jamison, D., Lawrence, L., and Murray, C. (2001). Modelling the effects of health on economic growth. *Journal of Health Economics*, Vol. 20:423–440.

Blackburn, K. and Cipriani, G. P. (2002). A model of longevity, fertility and growth. *Journal of Economic Dynamics and Control*, Vol. 26(No. 2):187–204.

Blanchard, O. J. (1985). Debt, deficits and finite horizons. *Journal of Political Economy*, Vol. 93(No. 2):223–247.

Bloom, D., Canning, D., and Fink, G. (2014). Disease and development revisited. *The Journal of Political Economy*, Vol. 122(No. 6):1355–1366.

Bloom, D., Kuhn, M., and Prettner, K. (2019). Health and economic growth. *Oxford Encyclopedia of Economics and Finance*. Oxford, UK: Oxford University Press.

Bloom, D. E., Canning, D., and Fink, G. (2010). Implications of Population Ageing for Economic Growth. *Oxford Review of Economic Policy*, Vol. 26(No. 4):583–612.

Bloom, D. E., Canning, D., Mansfield, R. K., and Moore, M. (2007). Demographic change, social security systems, and savings. *Journal of Monetary Economics*, Vol. 54(No. 1):92–114.

Boucekkine, R., de La Croix, D., and Licandro, O. (2002). Vintage human capital, demographic trends, and endogenous growth. *Journal of Economic Theory*, Vol. 104(No. 2):340–375.

Breyer, F., Costa-Font, J., and Felder, S. (2010). Ageing, health, and health care. *Oxford Review of Economic Policy*, Vol. 26(No. 4):674–690.

Cai, L. (2010). The relationship between health and labour force participation: Evidence from a panel data simultaneous equation model. *Labour Economics*, Vol. 17(No. 1):77–90.

Case, A. and Deaton, A. (2015). Rising morbidity and mortality in midlife among white non-Hispanic Americans in the 21st century. *PNAS*, Vol. 112(No. 49):15078–15083.

Cass, D. (1965). Optimum growth in an aggregative model of capital accumulation. *The Review of Economic Studies*, Vol. 32(No. 3):233–240.

Cervellati, M. and Sunde, U. (2005). Human capital formation, life expectancy, and the process of development. *American Economic Review*, Vol. 95(No. 5):1653–1672.

Cervellati, M. and Sunde, U. (2011). Life expectancy and economic growth: the role of the demographic transition. *Journal of Economic Growth*, Vol. 16:99–133.

Cervellati, M. and Sunde, U. (2013). Life expectancy, schooling, and lifetime labor supply: Theory and evidence revisited. *Econometrica*, Vol. 81(No. 5):2055–2086.

Cervellati, M. and Sunde, U. (2015). The effect of life expectancy on education and population dynamics. *Empirical Economics*, Vol. 48(No. 4):1445–1478.

Chakraborty, S. (2004). Endogenous lifetime and economic growth. *Journal of Economic Theory*, Vol. 116(No. 1):119–137.

Chen, H.-J. (2010). Life expectancy, fertility, and educational investment. *Journal of Population Economics*, Vol. 23(No. 1):37–56.

Christensen, K. and Vaupel, J. W. (1996). Determinants of longevity: genetic, environmental and medical factors. *Journal of internal medicine*, Vol. 240(No. 6):333–341.

Cigno, A. (1998). Fertility decisions when infant survival is endogenous. *Journal of Population Economics*, Vol. 11:21–28.

Cipriani, G. P. (2014). Population aging and payg pensions in the olg model. *Journal of population economics*, Vol. 27(No. 1):251–256.

CMS.gov (2019). National Health Expenditures. Retrieved from `https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/NationalHealthExpendData/NationalHealthAccountsHistorical`.

Currie, J. and Schwandt, H. (2016). Inequality in mortality decreased among the young while increasing for older adults, 1990–2010. *Science*, Vol. 352(No. 6286):708–712.

de la Croix, D. and Licandro, O. (1999). Life expectancy and endogenous growth. *Economics Letters*, Vol. 65(No. 2):255–263.

Diamond, P. A. (1965). National debt in a neoclassical growth model. *American Economic Review*, Vol. 55(No. 5):1126–1150.

Dixit, A. K. and Stiglitz, J. E. (1977). Monopolistic competition and optimum product diversity. *American Economic Review*, Vol. 67(No. 3):297–308.

Dong, X., Milholland, B., and Vijg, J. (2016). Evidence for a limit to human lifespan. *Nature*, Vol. 538(No. 7624):257–259.

Dowell, D., Arias, E., Kochanek, K., Anderson, R., Guy, Gery P., J., Losby, J. L., and Baldwin, G. (2017). Contribution of Opioid-Involved Poisoning to the Change in Life Expectancy in the United States, 2000-2015. *JAMA*, Vol. 318(No. 11):1065–1067.

Dwyer-Lindgren, L., Bertozzi-Villa, A., Stubbs, R. W., Morozoff, C., Mackenbach, J. P., van Lenthe, F. J., Mokdad, A. H., and Murray, C. J. (2017). Inequalities in life expectancy among us counties, 1980 to 2014: temporal trends and key drivers. *JAMA Internal Medicine*, Vol. 177(No. 7):1003–1011.

Eggleston, K. N. and Fuchs, V. R. (2012). The new demographic transition: most gains in life expectancy now realized late in life. *Journal of Economic Perspectives*, Vol. 26(No. 3):137–156.

Fanti, L. and Gori, L. (2014). Endogenous fertility, endogenous lifetime and economic growth: the role of child policies. *Journal of Population Economics*, Vol. 27(No. 2):529–564.

Galor, O. and Weil, D. (2000). Population, Technology, and Growth: From Malthusian Stagnation to the Demographic Transition and Beyond. *The American Economic Review*, Vol. 90(No. 4):806–828.

García-Gómez, P. (2011). Institutions, health shocks and labour market outcomes across europe. *Journal of health economics*, Vol. 30(No. 1):200–213.

Gehringer, A. and Prettner, K. (2019). Longevity and technological change. *Macroeconomic Dynamics*, Vol. 23(No. 4):1471–1503.

Hansen, C. and Lønstrop, L. (2015). The rise in life expectancy and economic growth in the 20th Century. *Economic Journal*, Vol. 125:838–852.

Harper, S. (2014). Economic and social implications of aging societies. *Science*, Vol. 346(No. 6209):587–591.

Harper, S., Kaufman, J., and Cooper, R. (2017). Declining US Life Expectancy: A First Look. *Epidemiology*, Vol. 28(No. 6):54–56.

Heijdra, B. and Romp, W. (2008). A life-cycle overlapping-generations model of the small open economy. *Oxford Economic Papers*, Vol. 60(No. 1):88–121.

Jones, C. I. (1995). R&D-based models of economic growth. *Journal of Political Economy*, Vol. 103(No. 4):759–784.

Kontis, V., Bennett, J. E., Mathers, C. D., Li, G., Foreman, K., and Ezzati, M. (2017). Future life expectancy in 35 industrialised countries: projections with a Bayesian model ensemble. *The Lancet*, Vol. 389(No. 10076):1323–1335.

Koopmans, T. C. (1965). On the concept of optimal economic growth. In *The Econometric Approach to Development Planning*. Amsterdam: North Holland.

Kuhn, M. and Prettner, K. (2016). Growth and welfare effects of health care in knowledge based economies. *Journal of Health Economics*, Vol. 46:100–119.

Lichtenberg, F. R. (2004). Sources of U.S. longevity increase, 1960–2001. *The Quarterly Review of Economics and Finance*, Vol. 44(No. 3):369 – 389. Economics of Technological Change in Medical Care: Concepts, Measures and Models.

Lorentzen, P., McMillan, J., and Wacziarg, R. (2008). Death and development. *Journal of Economic Growth*, Vol. 13:81–124.

Oeppen, J., Vaupel, J. W., et al. (2002). Broken limits to life expectancy. *Science*, Vol. 296(No. 5570):1029–1031.

Olshansky, S. J., Passaro, D. J., Hershow, R. C., Layden, J., Carnes, B. A., Brody, J., Hayflick, L., Butler, R. N., Allison, D. B., and Ludwig, D. S. (2005). A potential decline in life expectancy in the united states in the 21st century. *New England Journal of Medicine*, Vol. 352(No. 11):1138–1145.

Preston, S. H. (1975). The Changing Relation between Mortality and Level of Economic Development. *Population Studies*, Vol. 29(No. 2):231–248.

Prettner, K. (2013). Population aging and endogenous economic growth. *Journal of Population Economics*, Vol. 26(No. 2):811–834.

Prettner, K. and Trimborn, T. (2017). Demographic change and R&D-based economic growth. *Economica*, Vol. 84(No. 336):667–681.

Prettner, K. and Werner, K. (2016). Why it pays off to pay us well: The impact of basic research on economic growth and welfare. *Research Policy*, Vol. 45(No. 5):1075–1090.

Ramsey, F. P. (1928). A mathematical theory of saving. *The Economic Journal*, Vol. 38(No. 152):543–559.

Reinhart, V. R. (1999). Death and taxes: their implications for endogenous growth. *Economics Letters*, Vol 62(No 3):339–345.

Romer, P. (1990). Endogenous technological change. *Journal of Political Economy*, Vol. 98(No. 5):71–102.

Roser, M. (2019). Economic growth. *Our World in Data.* https://ourworldindata.org/economic-growth.

Samuelson, P. A. (1958). An exact consumption-loan model of interest with or without the social contrivance of money. *Journal of Political Economy*, Vol. 66(No. 6):467–482.

Solow, R. M. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics*, Vol. 70(No. 1):65–94.

Strulik, H., Prettner, K., and Prskawetz, A. (2013). The past and future of knowledge-based growth. *Journal of Economic Growth*, Vol. 18(No. 4):411–437.

Strulik, H. and Vollmer, S. (2013). Long-run trends of human aging and longevity. *Journal of Population Economics*, Vol. 26(No. 4):1303–1323.

Wolfe, B. (1986). Health status and medical expenditures: Is there a link? *Social Science & Medicine*, Vol. 22(No. 10):993–999.

World Bank (2019). World Development Indicators & Global Development Finance Database. Available at: `http://databank.worldbank.org/data`.

Yaari, M. E. (1965). Uncertain lifetime, life insurance and the theory of the consumer. *The Review of Economic Studies*, Vol. 32(No. 2):137–150.

Zhang, J. and Zhang, J. (2005). The effect of life expectancy on fertility, saving, schooling and economic growth: Theory and evidence. *Scandinavian Journal of Economics*, Vol. 107(No. 1):45–66.

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