

# The Genesis of the Golden Age: Accounting for the Rise in Health and Leisure\*

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**Abstract.** We develop a life cycle model featuring an optimal retirement decision in the presence of physiological aging. In modeling the aging process we draw on recent advances within the fields of biology and medicine. In the model individuals decide on optimal consumption during life, the age of retirement, and (via health investments) the timing of their death. Accordingly, “years in retirement” is fully endogenously determined. Using the model we can account for the evolution of age of retirement and longevity across cohorts born between 1850 and 1940 in the US. Our analysis indicates that 2/3 of the observed increase in longevity can be accounted for by wage growth, whereas the driver behind the observed rising age of retirement appears to have been technological change in health care. Both technology and income contribute to the rise in years in retirement, but the contribution from income is slightly greater.

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*JEL:* D91, I15, J17, J26.

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## 1. INTRODUCTION

A 20 year-old US male who was born in 1850 could expect to live another 43.7 years upon reaching his 20th birthday; in the 1940 cohort the same number had gone up by more than a decade. At the same time the age of retirement only rose by two years, implying an increase in length of retirement by roughly eight years (Lee, 2001).<sup>1</sup> What were the main driving forces behind the impressive increase in longevity? What drove the changes in the age of retirement? Can the observed increase in years in retirement be expected to continue in the years to come? In an era where the global population is aging rapidly, these are all relevant and important issues to resolve; not least because of the fiscal sustainability problems that are created by an aging global population. In this paper we attempt to offer some progress in this regard.

In the present study we develop a life-cycle model where the representative individual is subject to physiological aging. In modeling the aging process as increasing frailty we draw on recent research in the fields of biology and medicine. In our life cycle model aging has three substantive implications: it gradually lowers wage earnings over the life cycle; it works to increase the disutility from work, and it eventually leads to death. Within this framework the individual consumes, saves, and makes deliberate investments in slowing down the aging process thus postponing death. In addition, the individual decides when to optimally retire. In the end, the model allows us to study the impact from income and health technology (broadly defined) on changes in longevity, age of retirement, and thus years in retirement.<sup>2</sup> Formally, the model below extends the framework developed

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<sup>1</sup> It is well known that the labor force participation rate for older individuals has declined monotonically from the 19th century (Costa, 1998; Lee, 2001). From this evidence it is tempting to conclude that the *age of retirement* also must have been monotonically declining. This is not so, as discussed below in the context of our cohort analysis.

<sup>2</sup> Technically, technology improvement in our model means that any dollar amount of investment in health is more effective in slowing down the aging process. As a result, “technology” could be anything from improvements in health institutions to scientific discoveries leading to a better mode of conduct at the individual level (washing hands more often in response to the discovery of the germ theory, for instance) or breakthroughs that are more of the nature of “Big Medicine” (e.g., blood pressure controlling medicine).

in Dalgaard and Strulik (2010, 2014) so as to allow for optimal retirement, age-related disutility from work and a wage rate that changes over the life cycle.

We proceed to calibrate the model so that it reproduces observed aging, death and health expenditures for the US cohort that was born in 1940. Subsequently, we use the calibrated model to analyze the evolution of longevity and age-of-retirement across cohorts born from 1850 to 1940. We focus on these cohorts as they have all (largely) retired, which means our models' predictions can be compared to observed rather than estimated age of retirement.

In so doing we establish three main results. First, the increase in life expectancy at age 20 is mainly driven by income, propelling investments in health; 2/3 of the increase in longevity can be accounted for by wage growth. Second, technological progress in health care is responsible for the observed increase in age of retirement for individuals born between 1850 and 1940. Finally, our simulations show that as for years in retirement both income and technological change contributed over the period in question, with the income channel being somewhat stronger. As noted below various explanations for the rise in the importance of retirement have been put forward in the literature. While income is a familiar explanation for the rise of retirement, we believe this paper is the first to suggest that technological change in health was a contributor.

Analytically, wage income increases longevity for a simple reason. If an increase in income is solely spend on increasing consumption at the "intensive margin" (i.e., more per period consumption) the utility gains will diminish rapidly. As a result, it is a superior strategy to expand consumption along an "extensive margin" (i.e., by an increasing length of life), which can be attained by making investments that slow down aging. Consequently wages increase longevity. At the same time, we show that wages hold an ambiguous effect on age of retirement. As a result, wage growth is unlikely to have caused the observed path of age of retirement. But it does contribute significantly to an increase in years in retirement, though primarily via longevity.

In contrast, technological change in health care works to increase the age of retirement. The intuition is the following. When technology in health improves, individuals age more slowly; both because of a direct impact from the innovation and because of a behavioral response in the direction of more health investments. As a result, the disutility from work declines, inducing individuals to stay on longer in the labor market. In addition, a lower per period consumption level, prompted by greater health investments, elevates the utility gain from working. Hence, technology promotes both longevity and extends working life. While wage growth accounts for a big part of the observed increase in adult life expectancy, the increase in age of retirement is caused by technology. Since technological change both raises longevity and age of retirement, the net impact on years in retirement is theoretically ambiguous. With the aid of the calibrated model however we find that technological change, like wage growth, has worked to increase years in retirement, on net.<sup>3</sup>

The present paper is related to several strands of literature. Our work is related to the literature which models optimal health investments and longevity (e.g., Grossman, 1972; Ehrlich and Chuma, 1990). Kuhn et al. (2012) is particularly related as the authors develop a life cycle model where retirement is optimally determined, in the presence of life prolonging health investments. The authors explain how annuity markets (motivated by uncertain length of life) might lead to overinvestment in longevity, and discuss policy options to restore the first best. Wolfe (1985) and Galama et al. (2009) discuss the implications of retirement in the context of a Grossman (1972) model. In Wolfe (1985), however, retirement is not determined by way of utility maximization, and in Galama et al (2009) longevity is not affected by health investment. None of the mentioned studies analyzes the historical origins of rising years in retirement and longevity.<sup>4</sup>

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<sup>3</sup> We also examine the impact of changes in the relative price of health investments. From an empirical standpoint, however, this relative price has - if anything - been on the rise during the period in question, which the model suggests works to lower life expectancy and age of retirement. As a result, the observed rise in age of retirement seems to derive from technological change. Moreover, our analysis suggests that the impact from prices on years in retirement appears to be modest.

<sup>4</sup> In a general equilibrium setting the evolution of life expectancy and its interplay with growth as been studied by e.g. Cervellati and Sunde (2005), Hazan and Zoabi (2006) and Galor and Moav (2007). See

In the analysis below we contrast the impact of changes in income with those pertaining to technology vis-a-vis changes in longevity. This resonates with the debate on whether the observed increase in life expectancy (at birth) was due to income and nutrition (McKeown, 1976; Fogel, 1994) or technological knowledge (Preston, 1975; 1999). Our focus is different in that we study longevity at age 20. But in the context of “adult longevity” for cohorts born 1850-1940, we find that the income channel (here mediated by “health investments” rather than nutrition *per se*) seems to have been the relatively more powerful engine for life extension.

Also related are studies that examine “the rise of retirement” (e.g., Sala-i-Martin, 1996; Gruber and Wise, 1998; Kalemli-Ozcan and Weil, 2011; Bloom et al., 2007, 2011). Among these studies Bloom et al. (2011) is particularly related. Bloom et al. (2011) develop a life cycle model and use it to gauge the impact of changes in income and life expectancy on age of retirement using cohort data for the US. The authors find income to have been the most important driver of age of retirement. We obtain a different result since aging is endogenous in our model. This difference in modeling strategy allows us to capture technological change in health care in the first place. Moreover, our model adds another channel through which income matters to retirement: that greater income admits health improvements, which reduces the individual’s disutility from work and promotes a longer work-life. In the calibration this additional channel serves to “mute” the total effect of income on retirement compared to the Bloom et al. (2011) setting.<sup>5</sup>

Finally, this research is related to a recent literature which tries to explain the long-run evolution of macroeconomic aggregates in the US, such as health expenditures (Hall

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also Heijdra and Romp (2009) who analyse the impact from pension reform in a general equilibrium setting, in the presence of a realistic (but exogenously given) mortality process.

<sup>5</sup> Kalemli-Ozcan and Weil (2011) point out that the 20th century has witnessed a decline in uncertainty about life expectancy which may have helped propel the desire for early retirement; their numerical experiments suggest, however, that income should be a quantitatively more important determinant. Sala-i-Martin (1996) argues technological change has served to dilute the human capital of older workers making publically funded early retirement programs desirable; Gruber and Wise (1998) also highlight public retirement programs along with the tax disincentives for remaining in the labor market. Hence, pointing to an important impact from *health* technology on years in retirement appears to be a novel notion in this literature.

and Jones, 2009), leisure (Ramey and Francis, 2009) or schooling (Restuccia and Vanderbroucke, 2013). To this list we add life expectancy (at age 20) along with years in retirement.<sup>6</sup>

The paper proceeds as follows. The next section describes the model, which is calibrated in Section 3. Section 4 discusses comparative statics, whereas Section 5 provides our cohort analysis of longevity and retirement. A final section is reserved for concluding remarks.

## 2. THE MODEL

**2.1. Physiological Basics: Deficit Accumulation.** Our theory is built upon a physiologically founded notion of human aging: Aging is defined as the intrinsic, cumulative, progressive, and deleterious loss of function that eventually culminates in death (Arking, 2006). In gerontology the fact of aging is explained by applying reliability theory to the human body (Gavrilov and Gavrilova, 1991). That is, aging is understood as declining redundancy within the body in its totality. As redundancy recedes, expiry (“system failure”) becomes increasingly likely.<sup>7</sup> From an empirical perspective this process has been captured by the so-called frailty index, which is developed by Mitnitski and Rockwood and various coauthors in a series of articles (e.g., Mitnitski et al, 2002a,b; 2005; Rockwood and Mitnitski, 2006). This description is what we draw on in the following.

Specifically, we follow Dalgaard and Strulik (2014) and implement a parsimonious description of the process of health deficit accumulation (or increasing frailty), which extends Mitnitski et al. (2002a,b) by allowing health expenditure and technology to have an impact on aging. In concrete terms, health deficits  $D$  are evolving with age  $t$  according to

$$\dot{D}(t) = \mu(D(t) - a - Ah(t)^\gamma), \quad D(t) \leq \bar{D}, \quad (1)$$

<sup>6</sup> See also the interesting debate on the link between life expectancy, schooling and growth within the US (Hazan, 2009; Cervalletti and Sunde, 2013; Hansen and Lønstrup, 2012; Strulik and Werner, 2013).

<sup>7</sup> As young adults the functional capacity of our organs is estimated to be tenfold higher than needed for mere survival (Fries, 1980); this functional redundancy declines as we age.

where initial deficits  $D(0)$  are given. The parameter  $a$  captures environmental influences on aging beyond the control of the individual, the parameters  $A > 0$  and  $0 < \gamma < 1$  reflect the state of the health technology, and  $h$  is health investment. While  $A$  refers to the general power of health expenditure in maintenance and repair of the human body, the parameter  $\gamma$  specifies the degree of decreasing returns of health expenditure; the larger  $\gamma$ , the larger the relative productivity of cost-intensive high-technology medicine in maintaining and repairing highly deteriorated human bodies. It is worth pointing out that the interpretation of  $A$  is necessarily a broad one; the parameter captures all factors that ensure that a dollar of health investment is more effective in slowing down aging. Accordingly, the list would include technological knowledge, the effectiveness of health care institutions etc. The parameter  $\mu$ , the “natural” rate of aging, is estimated with great precision by Mitnitski and Rockwood (2002a,b). In fully developed countries the average  $\mu$  is around 0.04; with each birthday the average citizen obtains four percent more health deficits. Finally, death occurs when health deficits reach an upper boundary  $\bar{D}$ . Direct evidence on the existence of an upper boundary for  $D$  is found in Rockwood and Mitnitski (2006).<sup>8</sup>

**2.2. Labor Supply and Wages.** In order to capture the labor market consequences of aging we assume that human productivity deteriorates as a result of mounting bodily deficits. Specifically, we assume that wages decline at the rate of deficit accumulation ( $\mu$ ). At the same time, however, technological progress tends to elevate wages at the exogenous rate  $\alpha$ .<sup>9</sup> Formally the wage at age  $t$  is given by

$$w(t) = w_0 (e^{\alpha t} - \kappa e^{\mu t}). \quad (2)$$

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<sup>8</sup> Dalgaard and Strulik (2014) provide an extensive comparison between the standard economic approach to aging, according to which humans are thought to accumulate “health capital” (Grossman, 1972) with our physiological approach, according to which humans accumulate “health deficits”. One empirical advantage of our approach is that it avoids the counterfactual prediction of the Grossman (1972) model that medical expenses are positively correlated with health (see e.g., Case and Deaton, 2005).

<sup>9</sup> See Bloom et al. (2011) for a similar approach to capture the impact of aging on wages; their approach however involves an impact from “health capital” rather than from “health deficits” in addition to exogenous technological progress.

Here,  $w_0$  denotes the initial wage at entry into the workforce. If we assume that  $\alpha < \mu$ , it follows that the wage profile is hump shaped over the life cycle, that there is a unique solution for the age of retirement, and that, once retired, individuals do not find it worthwhile to re-enter the workforce. Conceptualizing  $\alpha$  as aggregate productivity growth (of, say, 1.5 percent per year) and recalling that  $\mu$  is around 4 percent p.a. empirically, the assumption  $\alpha < \mu$  is plausible and thus adopted in the following. Finally,  $\kappa$  is a parameter which determines the peak of labor income along the life cycle,  $0 < \kappa < 1$ .

Our individual under investigation is assumed to own one unit of indivisible labor. At each age he decides whether to supply this labor endowment or not. We assume that the initial wage is high enough at the beginning of the working life such that he does indeed supply labor. Consequently there is a decision about optimal retirement at age  $R$ , which has to be taken together with the decision about optimal life-length  $T$ . We assume that the model's parameters support  $R < T$  so that the individual indeed retires before he dies.

**2.3. The optimization problem.** The individual maximizes utility from consumption  $c(t)$  over life, taking disutility from work into account. We are considering a representative member of a cohort, for which reason the maximization problem can be viewed as deterministic to a first approximation. By considering a deterministic framework we are following the mainstream economic literature on health, e.g. Grossman (1972), Ehrlich and Chuma (1990), Hall and Jones (2007).<sup>10</sup>

The initial age is for convenience normalized to zero. This is the age at entry in the workforce and will later be assumed to be at age 20 in the calibration. Life before 20 is thus summarized in the initial conditions. Furthermore, to avoid notational clutter, we suppress a time index denoting the birth year of the cohort. Summarizing, intertemporal utility is given by

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<sup>10</sup> In Strulik (2013) it is shown that the physiological approach to aging can be extended towards uncertain life time with insignificant impact on results albeit with substantial erosion of analytical tractability.



$$V = \int_0^T e^{-\rho t} \{u(c) - (\beta + v(D)) \cdot \ell\} dt. \quad (3)$$

with instantaneous utility from consumption  $u(c) = (c^{1-\sigma} - 1)/(1-\sigma)$  for  $\sigma \neq 1$  and  $u(c) = \log(c)$  for  $\sigma = 1$  and  $v(D) = D^\nu/\nu$ . The parameter  $\rho$  is the rate of time preference and  $\ell \in \{0, 1\}$  is a toggle-variable that assumes the value of unity if the individual is working. The disutility from work depends positively on health deficits. The positive parameters  $\nu$  and  $\beta$  control the impact of health on utility before retirement. This approach is similar to that adopted in Bloom et al. (2011).

Besides labor income the individual receives a capital income from wealth  $k$ , which bears interest at rate  $r$ . We do not restrict  $k$  to be non-negative, so there may be periods in life, where it is optimal to go into debt and  $k$  is therefore negative. At death we assume (wolog) that  $k(T) = \bar{k} \geq 0$ . Thus the individual is assumed to inherit wealth  $k(0) = k_0$ , and to leave a bequest  $k(T) = \bar{k}$  (which both could be zero).

Income can be spend on consumption goods  $c$  or on health goods  $h$ . The relative price of health goods is  $p$ . While consumption goods are directly utility enhancing, health goods are instrumental in repairing or delaying bodily decay and, ultimately, in prolonging the life-span during which consumption goods can be enjoyed. In contrast to our earlier study, health expenditure also affects the retirement decision. The individual takes all prices as given, and both  $p$  and  $r$  are parametrically fixed. The law of motion for individual wealth is thus given by

$$\dot{k} = \ell[w + rk - c - ph] + (1 - \ell)[rk - c - ph]. \quad (4)$$

The problem is to maximize (3) subject to the accumulation equations (1) and (4), the wage schedule (2), the initial conditions  $D(0) = D_0$ ,  $k(0) = k_0$ , and the terminal conditions  $k(T) = \bar{k}$ ,  $D(T) = \bar{D}$ . The problem can be solved by employing optimal control theory; the state variables are  $k(t)$  and  $D(t)$  and the control variables are consumption  $c(t)$ , health investments  $h(t)$ , and the work decision ( $\ell$ ).

**2.4. Optimal Aging, Retirement, and Death.** From the first order conditions for consumption, health expenditure and age of retirement  $R$  we obtain (see Appendix for details):

$$g_c \equiv \frac{\dot{c}}{c} = \frac{r - \rho}{\sigma} \quad (5)$$

$$g_h \equiv \frac{\dot{h}}{h} = \frac{r - \mu}{1 - \gamma}. \quad (6)$$

$$\beta + \frac{D(R)^\nu}{\nu} = w(R)c(R)^{-\sigma} \quad (7)$$

Equation (5) is the standard consumption Euler equation, whereas equation (6) is the “Health Euler”. The Health Euler implies that a higher real rate of interest will induce individuals to allow health expenditure to rise over the life cycle; with a higher marginal rate of transformation it becomes attractive to postpone consumption by prolonging life (i.e., more consumption along the “extensive margin”, in this case). This growth is tempered however by the natural rate of aging,  $\mu$ . The intuition is that if  $\mu$  is high, health deficits accumulate fast at the end of life, which make late-in-life health investments relatively ineffective in prolonging life; instead the optimal strategy is to invest early in life (i.e., “prevention”). The optimal path for health expenditures is also influenced by the degree of diminishing returns in investments  $\gamma$ : intuitively, the greater the degree of diminishing returns the more attractive it will be to smooth health investments.

The condition (7) says that at the age of retirement,  $R$ , the disutility from supplying labor  $\beta + D(R)^\nu / \nu$ , in which  $D(R)$  represents health deficits at  $R$ , must equal the marginal utility gain from labor supply, captured by the marginal utility from consuming ( $c(R)^{-\sigma}$ ) times the additional wage income ( $w(R)$ ).

Early in life (i.e., at age  $t < R$ ) the above equation is not fulfilled with equality; rather the right hand side exceeds the left hand side. As noted above, this is essentially due to the fact that health deficits  $D$  are small early in life, and because wages are relatively high. During life, however, individuals suffer physiological decay, which works to increase the costs of labor supply, via rising deficits, and (eventually) lowers the gains via lower

wages. At time  $R$  the individual is indifferent between work or leisure, at which point he retires.

Now, consider the consequences of a higher wage level; this corresponds to an experiment in which the wage *profile* of the individual is shifted up, implying greater life-time wages.<sup>11</sup> There are three individual channels that influence the individual retirement choice: a health channel; an opportunity cost channel and a channel which operates through the level of consumption.

The first channel is that as wages increase individuals will respond by investing more in health, which lowers deficits at any given age and thus serves to delay expiry. This “health effect” will work to delay retirement, by lowering disutility from work. We elaborate on the intuition below, in the context of comparative statics.

The second channel is that as the wage profile shifts up the opportunity cost of leisure rises, enticing the individual to stay on a little longer in the labor market. Hence, the opportunity cost channel will also work to delay retirement.

The third channel, however, renders the overall link between income and retirement ambiguous. Higher wages work to increase the level of consumption, which implies lower marginal utility from additional work effort and concordant wage income. Consequently, the “enjoyment” of the incremental wage addition from staying in the labor market a little longer, is reduced. This channel then provides individuals with an incentive to retire a little earlier, thereby increasing their overall utility by increasing leisure rather than consumption.

Given these fundamental trade-offs in human behavior it is *a priori* unclear how the age of retirement (and thus years in retirement) will change if income rises. Accordingly, in order to answer this question we need to calibrate the model. This is done below, where the parameters of the model are chosen such that the model matches behavior of the average US male citizen (born in 1940) in several dimensions such as in terms of the evolution of frailty, health investments over life, and more. With the calibrated model in

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<sup>11</sup> Formally,  $w_0$  in equation (1) is shifted up: wages are thus higher at all points in time during life.

hand it is possible to conduct experiments, whereby parameters are changed after which the consequences for aging, longevity and retirement can be assessed. We return to this below.

At the time of death the boundary conditions  $k(T) = \bar{k}$  and  $D(T) = \bar{D}$  have to be fulfilled. That is, the lethal number of health deficits has been attained, and the capital stock has been eroded to the level of intentional bequests. Integrating (1) and (4) this means that conditions (8) and (9) have to hold. Observe that  $\ell = 1$  for  $t \leq R$  and  $\ell = 0$  otherwise. Furthermore, an optimal solution of this free boundary value problem requires that the associated Hamiltonian assumes a value of zero at the time of expiry. This implies condition (10), see Appendix for details.

$$\bar{D} = D_0 \exp(\mu T) - a [\exp(\mu T) - 1] - \frac{\mu A h(0) \exp(\mu T)}{g_D} [\exp(g_D T) - 1], \quad (8)$$

$$\bar{k} \exp(-rT) = k_0 + \frac{w_0}{\alpha - r} [\exp((\alpha - r)R) - 1] - \frac{w_0 \kappa}{\mu - r} [\exp((\mu - r)R) - 1] \quad (9)$$

$$\begin{aligned} & - \frac{c(0)}{g_c - r} [\exp((g_c - r)T) - 1] - \frac{ph(0)}{g_D} [\exp(g_D T) - 1] \\ 0 = & v(T) + \beta \bar{D}^\nu + c(T)^{-\sigma} \{r\bar{k} - c(T) - ph(T)\} \\ & - \frac{c(T)^{-\sigma} ph(T)^{1-\gamma}}{\mu A \gamma} \{-\mu a - \mu A h(T)^\gamma + \mu B u(T)^\omega + \mu D(T)\} \end{aligned} \quad (10)$$

with  $c(T) = c(0)e^{g_c T}$ ,  $h(T) = h(0)e^{g_h T}$ ,  $u(T) = u(0)e^{g_u T}$ , and  $c(T) = (c(T)^{1-\sigma} - 1)/(-\sigma)$  for  $\sigma \neq 1$  and  $c(T) = \log(c(T))$  otherwise. The four equations (7) – (10) can be solved for the four unknowns:  $c(0)$ ,  $h(0)$ ,  $R$ , and  $T$ . Having found the optimal initial values and the optimal dates of retirement and death, the four-dimensional dynamic system (1) and (4) – (6) is fully specified and it can be integrated analytically to obtain the optimal life-cycle trajectories of  $c$ ,  $h$ ,  $k$ , and  $D$ .

### 3. CALIBRATION

We calibrate the model for the average male (white) US citizen who retired around the year 2000; our benchmark American thus originates from the cohort born in 1940. For

this cohort life expectancy at age 20, that is at the assumed age at entry into the labor force, was 54.3 and the age at retirement was 62.7.

We begin by calibrating the evolution of health deficits. Since the estimate of the rate of aging  $\mu$  is unavailable for the US we take from Mitnitski et al. (2002a) the estimate of  $\mu = 0.043$  for Canadian men. The rate of aging within the USA and Canada appears to be similar enough to justify this as a good approximation (Rockwood and Mitnitski, 2007). Using the estimate  $g_h = 0.021$  for the growth rate of health expenditure over age from Dalgaard and Strulik (2014) and the estimate  $r = 0.06$  from Barro et al. (1995), we obtain from the Health Euler (7) the estimate  $\gamma = 1 - (r - \mu)/g_h = 0.19$ .

From Mitnitski et al.'s (2002a) regression analysis we back out initial deficits  $D_0 = D(20) = 0.0274$  as the relevant initial value for a 20 year old and  $\bar{D} = 0.1005$  54.3 years later at the expected expiry of the benchmark citizen. Before 1840 there was no visible trend for adult life expectancy in the US and we take the average life-expectancy at 20 of cohorts born between 1780 and 1840, which was about 62 years (Pole, 1992), as life expectancy without the benefits from medical technological progress. This assumption produces the estimate  $a = 0.013$  so that the model predicts a life-expectancy at 20 of 42 years without health investment. The 1850 cohort seems to be the first cohort from which on life expectancy begins to increase permanently (see Section 5).

For the benchmark run we employ data on the annual labor income by cohort (see Appendix for details). From this series we take the wage in 1960; that is, the year when our benchmark citizen (born 1940) is assumed to enter the labor force. Assuming an average annual growth rate of labor productivity of 1.5 percent we set  $\kappa = 0.13$  so that annual labor income peaks at the age of 55 at a value of about 1.2 times the labor income at age 30, as observed by French (2005).

Since consumption tends to be essentially constant across the life cycle, once family size has been taken into account (Browning and Ejrnæs, 2009), we put  $\rho = r$ . We normalize the relative price of health to unity and adjust the remaining parameters of the utility function and the technology parameter  $A$  such that (i) death occurs at the moment when

$\bar{D}$  health deficits have been accumulated at the age of 74.3; (ii) such that the individual retires at the age of 62.7; (iii) such that the health expenditure approximates average expenditure of American adults at the point of retirement (Keehan et al., 2004); (iv) and such that the wage elasticity of retirement is consistent with the historical record of the age at retirement across cohorts. This provides the estimates  $A = 0.00138$ ,  $\sigma = 1.15$ ,  $\nu = 0.65$ , and  $\beta = 0.035$ .

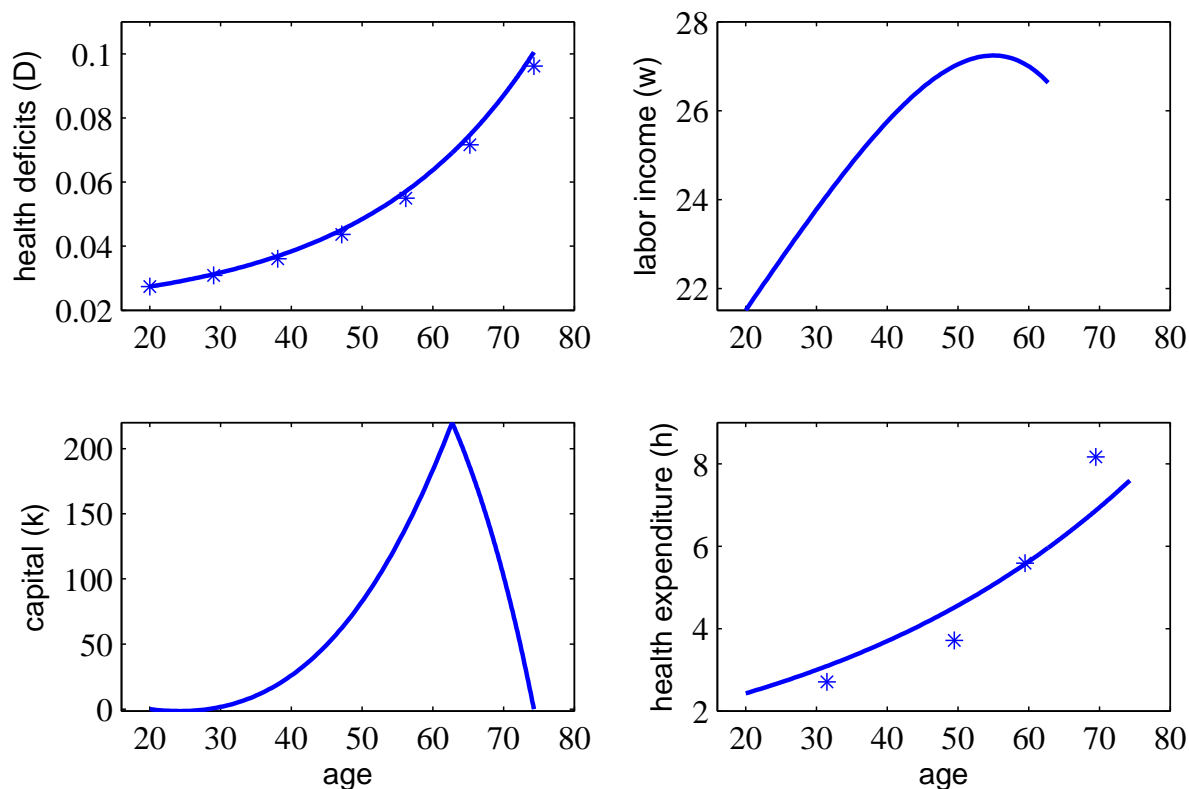
The calibrated intertemporal elasticity of substitution for consumption is close to unity as suggested by several recent studies (see e.g. Chetty, 2006). The external validity of  $\nu$  is harder to gauge. But as alluded to above, the selected value ensures that the model is able to replicate the historical evolution of age in retirement and years in retirement, as seen below. Different values for  $\nu$  do not change the qualitative properties of the model, in terms of comparative statics, as discussed in the next section. But it makes a difference vis-a-vis the model's ability to replicate the historical time series, as discussed in Section 5.

In order to focus on health expenditure and retirement as a motive for savings we assume  $k(0) = k(T) = 0$ . This rules out intentional bequests, which seem to play an unimportant role for the savings decision of average Americans (see de Nardi et al., 2010).

Figure 1 shows the obtained life cycle trajectories. Stars in the upper left panel indicate data according to Mitnitski et al.'s estimate of the age-specific frailty index. We have calibrated the upper and lower end of the frailty trajectory; the trajectory in between, however, is a prediction of the model. It fits the data well. The upper right panel shows the imposed wage trajectory.

The lower right panel shows the resulting trajectory of health expenditure. Stars indicate the actual health expenditure by age-group from Keehan et al, (2004), which can be compared to the solid line representing the prediction from the calibrated model. Admittedly, our calibration predicts a bit too much health expenditure in young ages and fails to match the actual expenditure for the oldest age group. But the model does well on average.

FIGURE 1: AGE PROFILES: COHORT BORN 1940



Solid lines: model prediction. Stars: data. Labor income is annual labor income in 1000 \$. Capital is wealth in 1000 \$. Health expenditure is annual health expenditure in 1000 \$.

The lower left panel shows how wealth evolves with age. Since individuals wish to have health expenditures grow over time they save early in life, thus building up wealth. The hump shaped wealth trajectory reaches its maximum at the age of retirement after which the individual dissaves until death.

#### 4. COMPARATIVE STATICS

The model involves three key exogenous variables: wages, prices and technology. Table 1 reports the comparative static results from a change in each of these variables. Table 1A reports the results from increases in the exogenous variables  $(A, w_0, p)$  by a factor  $1/3$  (which could be attained (say) by a constant growth rate of 1.5 % per year over two decades), whereas Table 1B show comparative statics associated with a decline in each of the variables by  $1/3$ . Note that since the system is highly non-linear the results need not be symmetrical.

To interpret the results we begin with the impact of wages. An increase in  $w_0$  by 1/3 evidently increases longevity by about 1.3 years. The reason is easy to grasp. If the individual were to spend his additional income solely on greater per period consumption it would involve sharply diminishing marginal utility. To avoid this situation it is attractive to expand consumption along the extensive margin instead; i.e., via a longer life. But this dictates more health investments so as to postpone the date of expiry. In the experiment health spending over the life cycle therefore increases by about 47 percent (cf. column 3). From Table 1B we see the results from a reduction in wages by 1/3: life expectancy and health expenditures decline, as expected.

Interestingly, when wages go up the age of retirement increases by about three weeks (Table 1A, column 2). This modest impact is to be appreciated in the light of the discussion in Section 2.4.: in our calibration the three countervailing effects from wage changes on age of retirement nearly cancel each other out. This point is nicely illustrated by the results pertaining to a reduction in wages (Table 1.B): a large reduction in wages delays retirement as well. Hence, at sufficiently lower wage levels the comparative static changes sign. In absolute value, however, the impact remains modest. Yet the result is worth emphasizing since it serves to illustrate the ambiguity of the effect of the wage on age of retirement. Moreover, in the next section, where we analyze historical time series, we will expect to see that pre-1940 wage increases predict a *declining* trend in age of retirement. The reason is that the model is calibrated to the 1940 cohort, implying that the simulation involves moving *backward* in time, which involves lower wages. As seen from Table 1B, at sufficiently low wage levels the impact from a wage increase on age of retirement is negative. Finally, whether we examine an increase or decrease in wages the net impact on *length of retirement* is positive, and largely caused by longer life.

Unsurprisingly, an increase in the relative price of health spending leads to a decrease in health spending. The consequence is a shorter life. Quantitatively longevity shrinks by about a year, as seen from the table. Meanwhile, the age of retirement also declines. In theory, price changes actually have two countervailing effects on retirement. On the



Table 1: Comparative Statics

A. Increase in...				B. Decrease in...			
	$\Delta T$	$\Delta R$	$(\Delta h/h)$		$\Delta T$	$\Delta R$	$(\Delta h/h)$
income ( $w_0$ )	1.37	0.06	46.8	income ( $w_0$ )	-1.65	0.09	-42.3
price ( $p$ )	-1.05	-0.94	-29.4	price ( $p$ )	1.71	1.44	63.1
technology( $A$ )	8.34	5.92	35.2	technology( $A$ )	-5.72	-5.83	-37.9

Table 1.A shows the results from increasing  $w_0, A, p$  by factor 1/3. Table 1.B provides corresponding results for a similar reduction. For the columns on  $\Delta T$  and  $\Delta R$  the units are “years” and  $(\Delta h/h)$  is measured in percent.

one hand the price increase encourages early retirement since it leads to a higher level of health deficits (due to lower health investments), which raises disutility from labor supply; on the other hand, when  $p$  increases real income declines and ordinary consumption  $c$  falls along with  $h$  (albeit less so), for which reason the marginal utility gain from staying on the labor market an additional year goes up. The latter effect promotes later retirement and leaves the overall effect of  $p$  on  $R$  ambiguous. In the calibrated version of the model, however, the former effect dominates. Accordingly, both death and retirement occur at an earlier point in life, but years in retirement increase. The economic significance of the impact is modest, at about five weeks (i.e., 0.1 year). Note that these results carry over to price reductions.

Finally consider the influence from health efficiency. Improvements in health efficiency makes it more attractive to expand utility from consumption along the extensive margin (longer life) relative to the intensive margin (more per period utility). Consequently the level of  $h$  increases (and  $c$  decreases), which leads to longer life (see column 3:  $h$  goes up by 35 percent). Quantitatively the impact is rather substantial: longevity rises by roughly eight years. At the same time the age of retirement also goes up. The reason is that a lower level of per period consumption increases its marginal utility, and thus the marginal benefits from additional wage work. This effect is reinforced by the fact that lower deficits reduce the marginal utility costs from staying in the labor market. While health efficiency improvements do increase the age of retirement (by 6 years) they also increase years in retirement by about 2.5 years. From Table 1.B. we note that the results

are qualitatively the same for a reduction in  $A$ , though the impact on years in retirement is smaller.

The general take-away from these experiments is that increases in either wages, relative prices of health spending, or improvements in health efficiency all will work to increase years in retirement. Quantitatively, income and health efficiency have roughly the same effect, whereas the influence from prices appears to be small. In the appendix we examine the robustness of these results to different values of  $\nu$ ; qualitatively and quantitatively the results are very similar to those reported in Table 1.

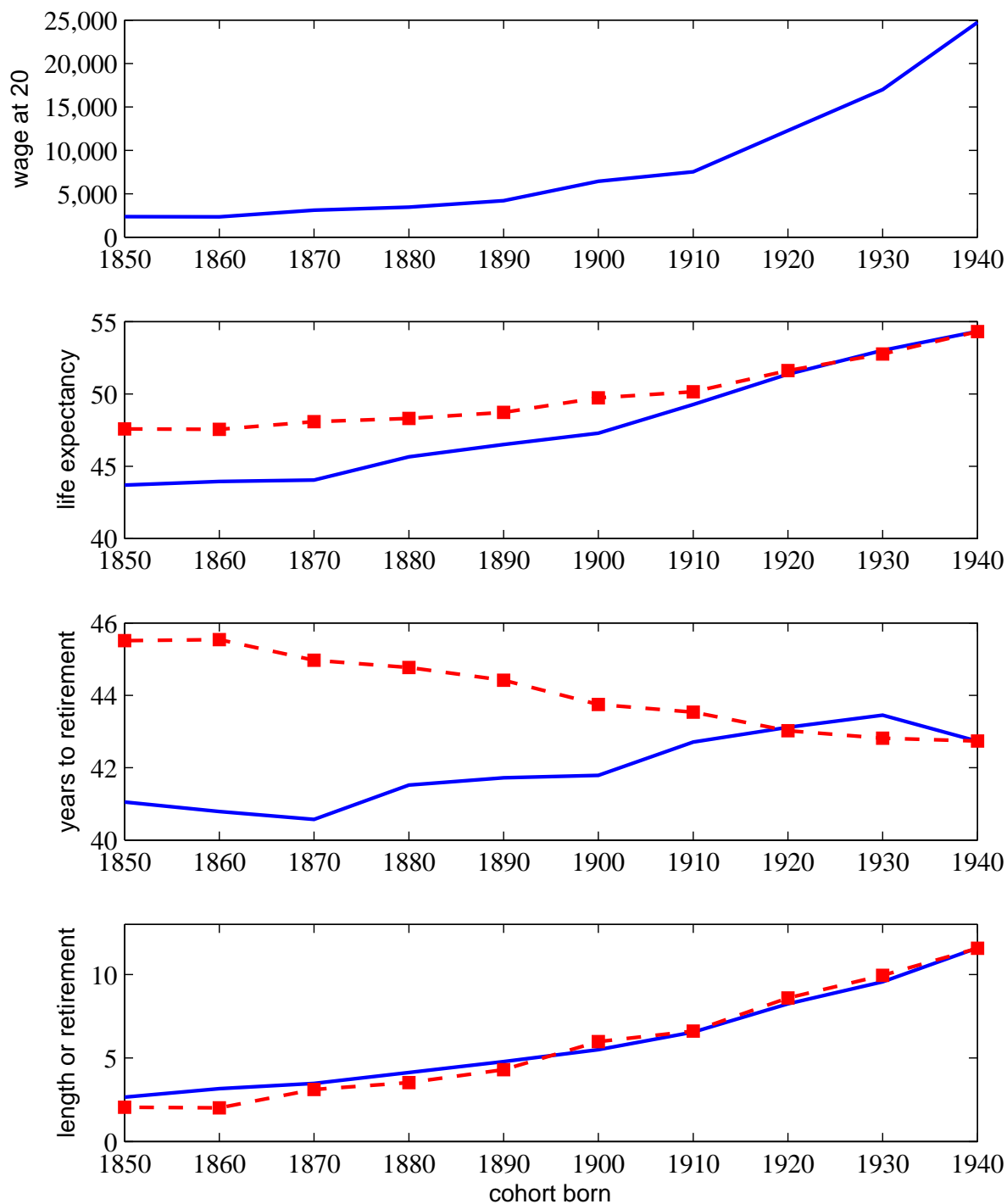
## 5. A CENTURY OF RISING HEALTH, WEALTH, AND LEISURE

In this section we examine the model's ability to replicate the movements in longevity, age of retirement and years of retirement across cohorts born 1850-1940 in the US. These cohorts are singled out since they have all (largely) left the labor market as of today, implying that the numbers for age of retirement are based on observation rather than estimation.

We have obtained data on average real wages by cohort, life expectancy by cohort, and age of retirement by cohort for the US. In addition, we have data on the evolution of the relative price of health services from 1928 onwards. Prior to 1928 we assume, inspired by the modest change in CPI, that the relative price of health services remained constant. We use the price series to calculate average prices per life time for the cohorts under scrutiny to proxy  $p$ . All data sources and manipulations are described in the Appendix. The data on wages, life expectancy, age of retirement and years in retirement are depicted in Figure 2 (cf. the solid blue lines).

It is probably worth pausing a moment to comment on the data, since it may seem surprising that the age of retirement (taken from Lee, 2001) is trending upward during most of the period in focus. To be sure, labor force participation rates (LFPR) among older males have declined drastically (and in a monotonic fashion) since the 19th century (Costa, 1998; Lee, 2001). Note, however, that the LFPR only captures individuals who manage to survive until 65; individuals who retired and died *before* the age of 65 do not

FIGURE 2: A CENTURY OF INCREASING HEALTH AND LEISURE: BASIC RUN



Solid lines: data. Dashed lines: model prediction with imputed wages and constant medical technology and prices.

count. As it turns out people started permanently leaving the labor force already at the age of 50 (Lee, 2001, p 643). Now, suppose improvements in health allow more people to

survive until the age of 65 after which they retire. Then the LFPR will decline, while the expected age of retirement will increase as individuals who in the past retired and died in their 50s manage to survive and retire in their 60s. There is therefore no contradiction between Lee's (2001) estimates that show a (slight) increase in age of retirement and the observed dramatic reductions in the LFPR of the old (Costa, 1998). That said, it is also worth observing that the age of retirement indeed starts to decline with cohorts born after 1930. This process continues during the post World War II period (Lee, 2001, Table 1). We return to this fact at the end of this section.

With the data in hand, along with our calibrated parameters, we provide the following cross-cohort analysis. First, we feed our real wage data (displayed in the top panel of Figure 2) through the model and compare the model's predictions for longevity and age of retirement to the data. As next steps one would ideally like to look at the influence from  $p$  and  $A$ , individually. Sadly, however,  $A$  is unobservable and our data on  $p$  is somewhat incomplete. Hence, we do the following instead. We start by filtering our data series for  $p$  through the model, and subsequently calibrate the series for  $A$  such that we match the evolution of longevity by cohort *exactly*. Notice that measurement error in the series for  $p$  (in particular the unobserved part) will be picked up by the calibrated  $A$  series. The key check of the model then becomes whether it is able to account for the observed evolution of cohort specific *age of retirement*, conditional on the series for  $A$ ,  $w$  and  $p$ . Notice that this procedure also allows us to assess how much of the observed increase in longevity and age of retirement we can account for by either wage changes or changes in  $p$  and  $A$ , conditional on our calibration.

In Figure 2 we show the result from the first exercise. As seen from panel 2 from above we cannot fully motivate the evolution of cohort specific life expectancy: the calculated increase due to wage growth is somewhat smaller than what is observed in the data. The model does replicate longevity for the cohort born in 1940 but this is a consequence of the calibration, since it was designed to match life expectancy at age 20 for individuals born precisely in 1940. The sign that wage growth falls short of accounting fully for the

path of longevity is thus found in the fact that the model overestimates longevity of the 1850 cohort. That said, the explanatory power of wage growth is substantial in that it can account for roughly 7 additional years in life expectancy ( $=54.3-47.6$ ), or roughly 2/3 of the total increase from the 1850 to 1940 cohort (i.e., 10.7 years). This means that the lions share of the total increase can adequately be accounted for by wage growth over the period in question.

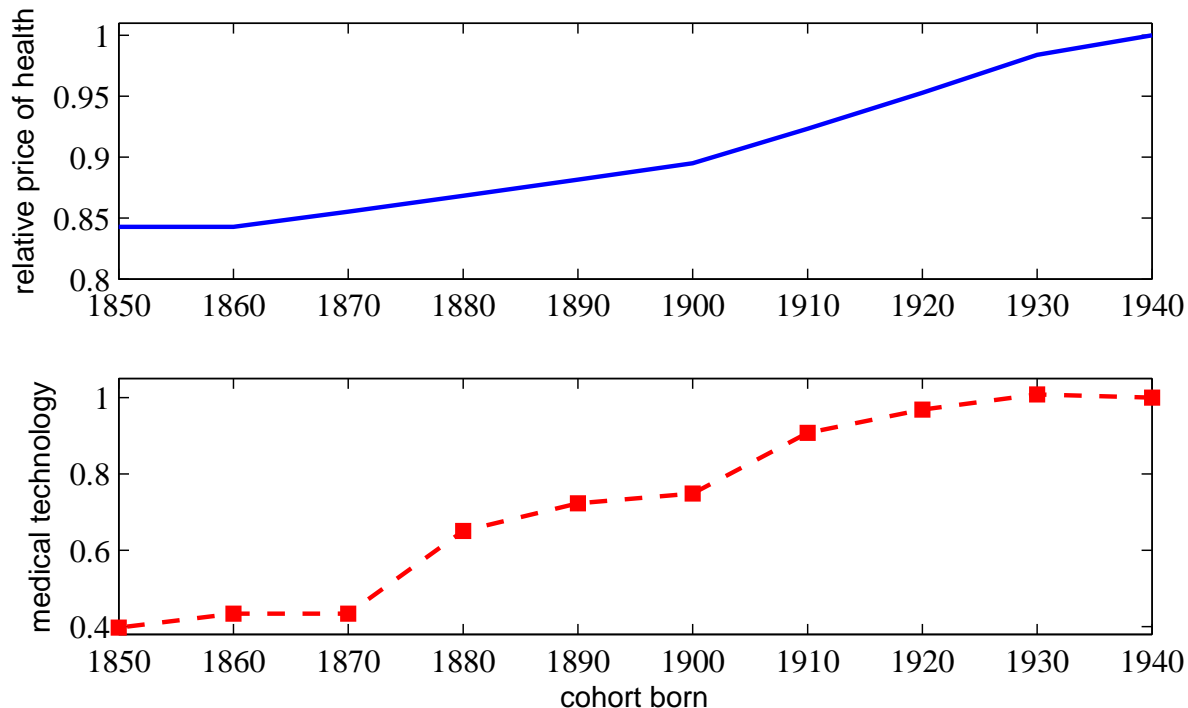
However, wage growth is clearly incapable of accounting for the trend in age of retirement; the exact match for the 1940 cohort is again a simple consequence of the calibration. As we saw in the last section wage growth works to lower the age of retirement, at wages substantially below their 1940 level. Accordingly, the model overestimates age of retirement in 1850; indeed, the simulation suggest that the age of retirement should progressively have dropped over time whereas in fact the opposite occurred. This exercise shows that wage growth is unlikely to have been the dominant force in accounting for the evolution of age of retirement between 1850-1940.

Even though the age of retirement evidently rose during most of the period that we consider, years in retirement nevertheless expanded monotonically, as shown in Figure 2. In this context, however, wage growth tends to overstate the increase slightly. This is reflected in the fact that the simulated number of years in retirement in 1850 is smaller than in the data. Absent changes in technology and prices the model suggest that a larger increase in years in retirement should have occurred.

Accordingly, we next try to gauge the (joint) influence from changes in prices and health efficiency on longevity and age of retirement. The calibrated series for  $A$ , which ensures that the model replicates the evolution of longevity, is depicted in Figure 3 along with our input data on price movements. As noted above the calibrated series for  $A$  is undoubtedly tainted by measurement error if the price series is inaccurate, which it may well be since we have no data prior to 1928. Still, movements in prices have a relatively modest quantitative impact on longevity compared to the impact from  $A$ , as documented in the last section. Consequently, as long as the measurement error in  $p$  is relatively

small the induced bias on the path of  $A$  will probably be insignificant. It therefore seems worthwhile to try to assess whether the path of  $A$  looks plausible as a representation of the evolution of health efficiency.<sup>12</sup>

FIGURE 3: IMPUTED PRICES AND PREDICTED MEDICAL TECHNOLOGY



Price data and calibrated series for medical technology.

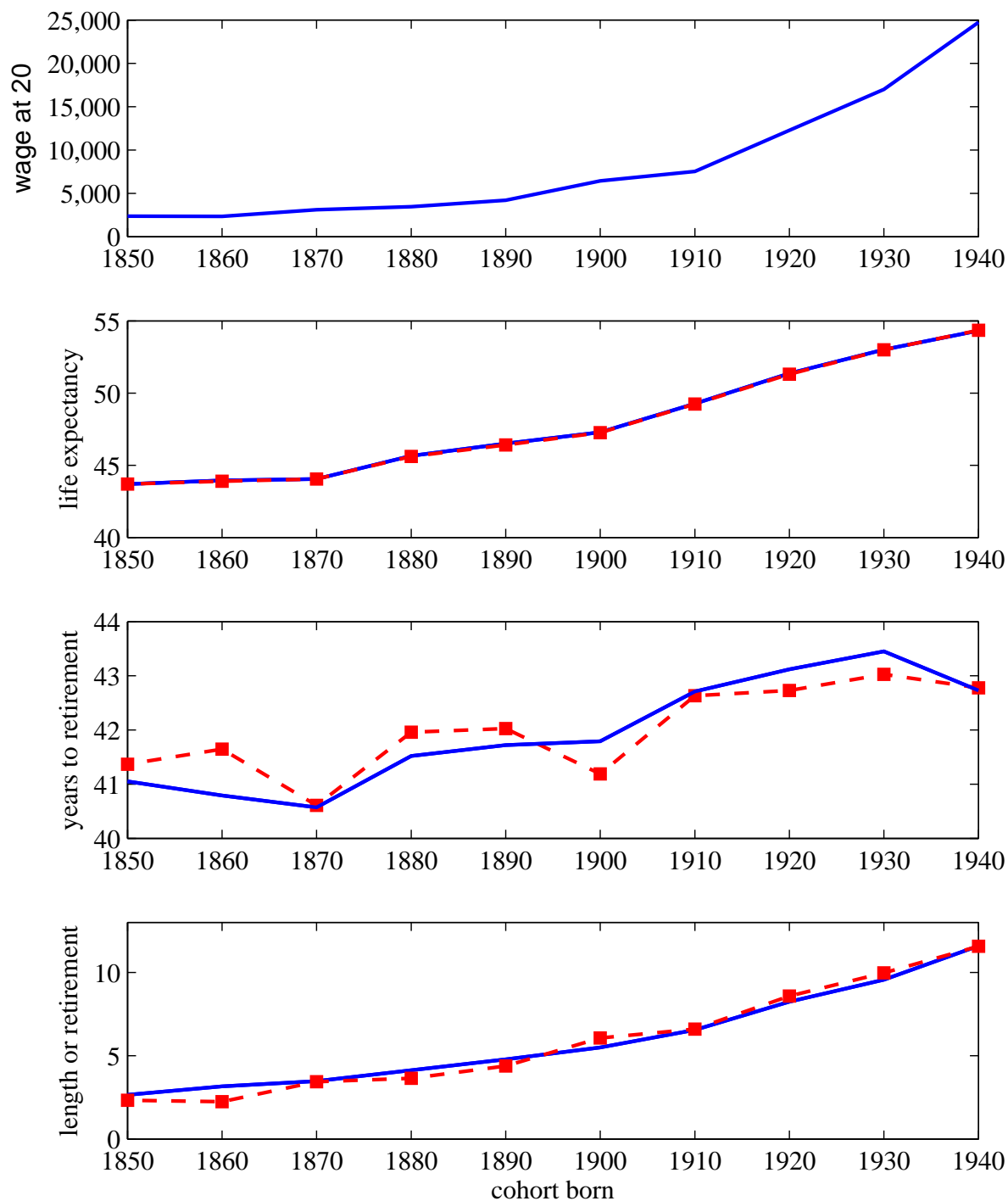
It is clear that the series features two major increases: from cohorts born in 1870 to cohorts born 1880-90, and again between the turn of the century and 1910-1920. Recall that longevity is measured as life expectancy at the age of 20; hence the question is whether major innovations can be said to have occurred during the period 1900-1910 (episode 1) and during the period 1930-40 (episode 2).<sup>13</sup>

A possible explanation for the first episode could be initiatives associated with the discovery of the germ theory of disease. While this theory, by all accounts, was scientifically accepted around 1880 it is probably not until the beginning of the 20th century that its

<sup>12</sup> The period under scrutiny also witnessed longevity-influencing events, such as World War I. The impact from such events will inevitably be picked up by  $A$  in this calibration.

<sup>13</sup> The major shifts are clearly between generations 1870 and 1880, and between generations 1900 and 1910. But in both cases the increase appears to continue for another generation (to 1890 and 1920, respectively) before it “stalls”.

FIGURE 4: A CENTURY OF INCREASING HEALTH AND LEISURE: IMPUTED PRICES



Solid lines: data. Dashed lines: model prediction with imputed wages and prices and estimated medical technological progress.

implications is starting to diffuse in society at large in the US, that is, the value of ventilated rooms, of washing hands, isolating sick individuals etc. (Preston, 1999). If indeed

these ideas started to spread at this time one would expect to see an increase in longevity of cohorts that were 20 around the turn of the century. The second episode involving a rising  $A$  might be associated with the discovery of penicillin in 1928 and its subsequent application in the 1940s. This is at least broadly consistent with Figure 3 although the initial upward shift in  $A$  seems to be a decade too early. Overall the calibrated series for  $A$  does not seem glaringly inconsistent with major health related innovations during the period in question.

Thus reassured, Figure 4 depicts the impact of changes in  $A, p$  and  $w_0$  on our main outcome variables; the panels mimic those from Figure 2. By construction the model matches life expectancy exactly. The key issue though is the model's fit with regards to the age of retirement. With our preferred value for  $\nu$  the model replicates it well. Hence, once we also take into account changes in the relative price of health and health efficiency, the model can match 90 years of persistent increases in health and leisure. But there is an important upshot. Since both price increases and wage growth work to lower the age of retirement we have a clear conclusion: the upward sloping path for age of retirement is due to the impact from technological change in health care.

Finally, the fit for years in retirement is also good. In part, of course, because we match longevity exactly. Nevertheless we now see that the model does not underestimate years in retirement appreciably in 1850. This suggests that while technology (and prices) do serve to increase years in retirement (cf. Table 1), their quantitative impact is more modest than that of income, and have therefore served to stabilize the evolution of years in retirement over the period in question.

As explained in Section 3 we have been unable to pin down an exact value for  $\nu$ . But the one chosen allows us to match the historical time series to the greatest possible extent, which is essential in order to provide a meaningful assessment of the relative impact from prices, income and technology on years in retirement. In the Appendix we show simulations for an alternative  $\nu$ ; the model fit is not as good. In particular, we do not match age of retirement very well. Hence, it is worth stressing that the “decomposition



results” above are contingent on choosing parameter values such that the model fits the within cohort data discussed in Section 3, and the time series movements depicted in Figures 3 and 4, to the greatest extent possible.

In the analysis above we have focused on cohorts born between 1850 and 1940. As noted in the Introduction, we focus on these cohorts as they have all (largely) retired from the labor market. Consequently, we can rely on observations (cohort estimates) on age of retirement rather than (cross sectional) period estimates. Nevertheless, it seems worth commenting on more recent developments.

The evidence reported in Lee (2001) shows that years in retirement have continued to expand with cohorts born after 1940: it rose from 11.6 years to 16.3 years for the cohort born in 1990. The further rise of retirement is driven by increasing life expectancy but also by a declining age of retirement: whereas the expected age of retirement was 63.5 for the cohort born in 1930 (the recorded “peak”), it declined to 61.5 in 1990. These changes suggest, seen through the lens of our model, that income and technological progress have been unable to off-set the impact from an accelerated rate of increase in the medical consumer price index (MCPI); the relative rate of increase in the MCPI went progressively up from 0.4% per year to 2.8% per year at the end of the century (Berndt et al., 2000, Figure 1). This, at least, can account for the declining age at retirement, combined with the continued increase in years in retirement, within the context of the model developed above. At the same time other mechanisms might well have been at work, encouraging earlier retirement (e.g., Gruber and Wise, 1998; Kalemli-Ozcan and Weil, 2011).

## 6. CONCLUSION

In the present paper we have developed a life cycle model with an optimal retirement choice where individuals are subject to physiological aging. We have used a calibrated version of the model to study the origins of the remarkable rise in adult life expectancy as well as the increase in the age of retirement, for cohorts born 1850-1940.

We find that the bulk of the increase in adult longevity appears to have been generated via an income-cum-health investment channel; about 2/3 of the total increase seems to

be due to income growth. Technological progress also contributed, but income appears to have been more important. Conversely, technological knowledge appears to have been largely responsible for the increase in age of retirement in the US, 1850-1940; income and rising prices work to drive the age of retirement in the other direction during this period.

From a policy angle the difference between longevity and age of retirement is perhaps of greater interest. The model predicts that increases in (relative) health care prices, technological progress in health care and rising income all contribute to more years in retirement. Since there is no particular reason to expect that either one of these factors will stall, this suggests that desired length of retirement will continue to grow in the years to come. This could be seen as bad news from the point of view of fiscal sustainability.

Since governments are unlikely to wish for technological regress and declining income, it would appear that the only option left to policy is to target relative prices of health care. Our calibration suggest that *declining* relative prices of health investments will serve to increase both longevity and the age of retirement, but that the impact on the latter appears to be larger, which would thus imply fewer desired years in retirement. Yet caution is warranted as these results might be specific to the US calibration. Moreover, the quantitative impact from even substantial reductions in prices appear to be modest.

APPENDIX

MATHEMATICAL APPENDIX

Integrating (1) provides the following solution.

$$D(t) = D(0) \exp(\mu t) - \int_0^t \mu a \exp(\mu(t-v)) dv - \mu A \int_0^t h(v)^\gamma \exp(\mu(t-v)) dv + \mu B \int_0^t u(v)^\omega \exp(\mu(t-v)) dv. \quad (\text{A.1})$$

Integrating (4) we get (A.2).

$$k(t) = k(0) \exp(rt) - \int_0^{\min\{t,R\}} \exp(r(t-v)) w(v) dv - \int_0^t \exp(r(t-v)) c(v) dv - \int_0^t \exp(r(t-v)) ph(v) dv. \quad (\text{A.2})$$

Using (A.1) and (A.2), the initial conditions  $D(0) = D_0$ ,  $k(0) = k_0$ , and the terminal conditions  $D(T) = \bar{D}$ ,  $k(T) = \bar{k}$ , the Lagrangian associated with problem (1)- (4) is given by

$$\begin{aligned} \max_{c,h,R,T} L = & \int_0^T e^{-\rho t} \frac{c^{1-\sigma} - 1}{1-\sigma} - \int_0^R e^{-\rho t} (\beta + D^\nu / \nu) dt \\ & + \phi \left\{ k_0 + \int_s^R e^{-rt} w(t) dt - \int_0^T e^{-rt} c(t) dt - \int_0^T e^{-rt} ph(t) dt - \bar{k} e^{-rT} \right\} \\ & + \lambda \left\{ D_0 - \mu a \int_0^T e^{-\mu t} dt - \mu A \int_0^T h(t)^\gamma e^{-\mu t} dt - \bar{D} e^{-\mu T} \right\}. \end{aligned} \quad (\text{A.3})$$

The first order conditions for consumption and health expenditure are:

$$0 = e^{-\rho t} c^{-\sigma} - \phi e^{-rt} \quad (\text{A.4})$$

$$0 = -\phi e^{-rt} p - \lambda \mu A \gamma h^{\gamma-1} e^{-\mu t}. \quad (\text{A.5})$$

Differentiating (A.4) with respect to time we get (5) and differentiating (A.5) with respect to time we get (6). The first order condition for optimal retirement is

$$-\left( \beta + \frac{D(R)^\nu}{\nu} \right) e^{-\rho R} - \phi w(R) e^{-rR} = 0$$

Inserting  $\phi$  from (A.4) provides (7) in the text.

Two conditions have to be fulfilled at the optimal  $T$ . The first one is that  $D(T) = \bar{D}$ . Evaluating (A.1) at  $T$  and employing the fact of constant growth rates of  $h$  and  $u$  according to (7) and (8) this can be expressed as:

$$\bar{D} = D_0 \exp(\mu T) - \mu a \int_0^T \exp(\mu(T-t)) dt - \mu A \int_0^T h(0)^\gamma \exp(\gamma g_h t) \exp(\mu(T-t)) dt$$

Solving the integrals provides (8) in the text. The second condition for optimal  $T$  is that the Lagrangian evaluated at  $T$  assumes the value of zero, that is, using (A.3) and the Euler equations (5)-(7):

$$\begin{aligned} 0 = & \left( \frac{c(T)^{1-\sigma} - 1}{1-\sigma} \right) \exp(\rho T) - (\beta + \bar{D}^\nu(\nu)) \exp(\rho T) \\ & + \phi \left[ -\exp(-rT)c(T) - p \exp(-rT)h(T) + r \exp(-rT)\bar{k} \right] \\ & + \lambda \left[ -\mu \exp(-\mu T) - \mu A h(T)^\gamma \exp(-\mu T) + \mu \bar{D} \exp(-\mu T) \right] \end{aligned}$$

Inserting from (A.4) and (A.5) that  $\phi \exp(-rT) = c(T)^{-\sigma} \exp(-\rho T)$  and that  $\lambda \exp(-\mu T) = -\phi \exp(-rT) \cdot p h(t)^{1-\gamma} / (\mu A \gamma)$  provides (10) in the text.

Using the Euler conditions (A.4)-(A.5) and the wage schedule (2) the budget constraint (A.2) can be written as:

$$\begin{aligned} 0 = & k(0) + w_0 \int_0^R \exp((\alpha - r)t) dt - w_0 \int_0^R \exp(-(\mu + r)t) dt \\ & - \int_0^T c(0) \exp((g_c - r)t) dt - p \int_0^T h(0) \exp((g_h - r)t) dt - \bar{k} \exp(-rT). \end{aligned}$$

Solving the integrals provides (9) in the text.

## DATA APPENDIX

- **Life expectancy at age 20 by cohort.** Source: Lee (2001, Table 1).
- **Expected age of retirement at age 20 by cohort.** Source: Lee (2001, Table 1).
- **Average years of schooling by cohort.** Source: Hazan (2009).
- **Nominal wage index for unskilled workers for the US.** Source: Historical statistics for the US millennium edition. Table Ba4218: Index of money wages for unskilled labor: 1774-1974.<sup>14</sup>
- **CPI for the US.** Source: Historical statistics for the US millennium edition. Table CC1-2: Consumer price indices for all items: 1774-2003.<sup>15</sup>
- **Real wages 1850-1940 for individual cohorts:** The real wage index for unskilled workers, at time  $t$ ,  $x_t$ , is calculated as the nominal wage (index =100 in 1860) divided by the CPI (index = 100 in 1860). In practise the average wage reflects educational attainment of the cohort. Hence, for cohorts born at time  $c$ , with  $u_c$  years of recorded schooling, the associated real wage index was calculated as

$$y_c = x_{c+20} \cdot e^{\theta \cdot u_c}. \tag{A.6}$$

<sup>14</sup> Web source: <http://hsus.cambridge.org/HSUSWeb/essay/showtableessay.do?id=Ba4218&swidth=1366>

<sup>15</sup> Web source: <http://hsus.cambridge.org/HSUSWeb/search/searchTable.do?id=Cc1-2>

Hence, we assume cohort  $c$  enters the labor market at age 20. The parameter  $\theta$  is the return to a year of schooling. We assume  $\theta = 0.1$  in all years. Finally, to get the wage *level*, we did the following. First, we obtained GDP per worker, `rgdpl2wok`, for 1970 from Penn World Tables 7.0 (1970 is the last year for which we have data on cohort specific years of schooling from Hazan, 2009). Second, we define  $z_t$  as  $2/3 \cdot \text{rgdpl2wok}_{1970}$ , where “2/3” proxies for the labor share. Third, for all cohorts  $c$  their entry real wage level is then calculated as

$$w_c = z_t \cdot (y_c/y_{1970}). \quad (\text{A.7})$$

• **The relative price,  $p$ .** We constructed  $p$  at an annual frequency (1850-2000) in the following way: Until 1927  $p = 1$ . After 1927 the  $p$  is allowed to rise with the relative rate of inflation (CPI vs MCPI) in the period intervals reported in Berndt et al (2000, Figure 1). For instance, between 1927 and 1946 the relative rate of increase in MCPI was 0.4 pct per year, rising progressively to 2.81 pct per year in the last period 1986-96. The relative speed of inflation from 1996 to 2016 (the terminal year of the 1940 cohort) is assumed identical to the period 1986-96.

#### SENSITIVITY ANALYSIS

The tables below report comparative static results comparable to those reported in the text. The alternative values of  $\nu$  and  $\beta$  are such that the *within* cohort match of model and data is the same as that shown in Section 3. However, the fit for the historical time series exercise is poorer (see below).

Table A.1: Comparative Statics:  $\nu = 1$

A.1.A. Increase in...				A.1.B. Decrease in . . .			
	$\Delta T$	$\Delta R$	$(\Delta h/h)$		$\Delta T$	$\Delta R$	$(\Delta h/h)$
$w_0$	1.34	-0.61	44.9	$w_0$	-1.63	0.95	-41.2
$p$	-1.06	-0.95	-29.6	$p$	1.72	1.37	62.8
$A$	8.32	5.16	32.6	$A$	-5.73	-6.23	-38.6

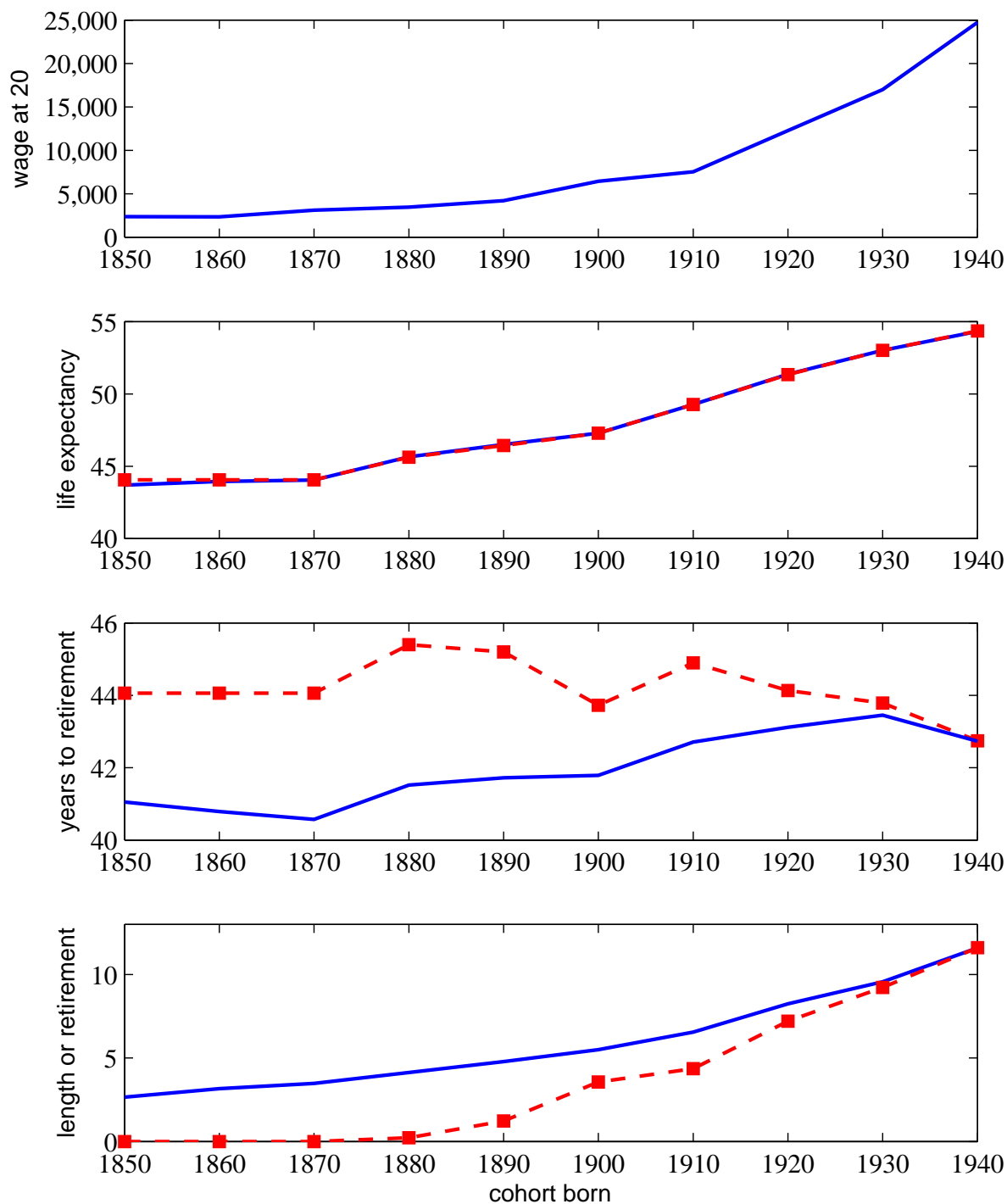
$\nu = 1$  requires to recalibrate  $\beta = 0.237$  such that the model supports the same retirement age as the benchmark calibration.

Table A.2: Comparative Statics:  $\nu = 2$

A.2.A. Increase in...				A.2.B. Decrease in ...			
	$\Delta T$	$\Delta R$	$(\Delta h/h)$		$\Delta T$	$\Delta R$	$(\Delta h/h)$
$+\Delta w_0$	1.31	-1.55	42.0	$-\Delta w_0$	-0.50	0.62	-13.8
$+\Delta p$	-1.06	-0.94	-29.6	$-\Delta p$	1.71	1.27	62.7
$+\Delta A$	8.29	4.29	31.8	$-\Delta A$	-5.74	-6.86	-39.4

$\nu = 1$  requires to recalibrate  $\beta = 0.303$  such that the model supports the same retirement age as the benchmark calibration.

FIGURE A.1: A CENTURY OF INCREASING HEALTH AND LEISURE:  $\nu = 1$



Solid lines: data. Dashed lines: model prediction with imputed wages and prices and estimated medical technological progress. Parameter values as for Figure 4 but  $\nu = 1$  and  $\beta = 0.237$ .

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