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Abstract

This paper integrates into public economics a biologically founded, stochastic process of individual ageing. The novel approach enables us to quantitatively characterize the optimal joint design of health and retirement policy behind the veil of ignorance for today and in response to future medical progress. Calibrating our model to Germany, we find that future progress in medical technology calls for a potentially drastic increase in health spending that typically should be accompanied by a lower pension savings rate and a higher retirement age. Interestingly, medical progress and higher health spending are in conflict with the goal to reduce health inequality.

Key words: Ageing; Health Expenditure; Health Inequality; Social Security System; Retirement Age.

JEL classification: H50; I10; C60.

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1 Introduction

Life expectancy of adults increased by around 15 years over the 20th century and many researchers in demography and the natural sciences consider it likely to increase further (e.g. Gavrilov and Gavrilova, 1992; Oeppen and Vaupel, 2002). The development was to a large extent driven by fast advances in medical and pharmaceutical research that led to substantial increases in the effectiveness of health spending on the ageing process.[1] Through this channel, health spending contributes to the widely discussed problem of social security systems, namely that pension benefits are likely to decline for a given pension savings rate unless the statutory retirement age is changed. This implies that health and pension policy shall be examined and designed jointly.

Higher effectiveness of medical technology may make higher contribution rates to public health insurance more desirable in order to better reap the benefits in terms of improved health and higher life expectancy. Its adverse effect on pension benefits could be offset by raising contributions to the pension system as well. There is, however, a trade-off between the two tiers of the social insurance system, as higher contributions to pension insurance and health insurance both reduce net income in the working period, for a given labor supply and because of a reduction in labor supply. Alternatively, it could be desirable to increase the retirement age along with an increase in health spending. In view of the complex linkages between the pension system and the health care system created by the endogeneity of human health and longevity, the jointly optimal design of our social insurance systems appears to be both important and *a priori* non-obvious.

This paper investigates the interactions between public health and pension policy in order to quantitatively characterize the optimal joint design of the social insurance system today and in response to future medical progress. In line with a long tradition in public economics to justify social systems, we focus on expected welfare maximization behind the

[1] Medical and pharmaceutical innovations became important drivers of life expectancy from the 1950s onwards. Before that, life expectancy rose predominantly because of decreases in child mortality rather than because of increases in life expectancy of adults (e.g. Milligan and Wise, 2011). In the US, the fraction of the population which is at least 65 years old is projected to be 18.8 percent in 2025, whereas it was 8.1 percent in 1950 (Poterba, 2014).

veil of ignorance.[2] It is based on the idea that an *ex ante* identical population would agree on a social insurance system which reduces the probability of illness and insures against social hardships and long life.[3] An interesting, related question is whether implementing an *ex ante* optimal health care system will reduce health inequality within a society, compared to the suboptimal status quo. In fact, reducing health inequality is a major goal of large organizations like the World Health Organization (WHO) and the European Union (EU).[4] It is, however, non-obvious whether it is line or in conflict with the goal to maximize *ex ante* welfare.

Our key innovation which enables us to examine these issues is to integrate into public economics a biologically founded process of individual ageing. Our approach is based on empirical evidence from gerontology[5] which suggests that (i) at any given age, the number of health deficits is approximately Poisson-distributed in the population, (ii) the average number of individual health deficits grows with age, and (iii) the probability of death at any age strongly depends on the number of health deficits an individual has accumulated over time (Mitnitski and Rockwood, 2002a, 2002b, 2005). Ageing is understood as the stochastic and individual-specific deterioration of the functioning of body and mind − represented by an accumulation of health deficits − that eventually culminates in death (Arking, 2006; Masoro, 2006). In economics, so far the approach has been exclusively employed to analyze life cycle decisions of a single agent.[6] In this paper, by contrast, we examine economy-wide

[2]Jones and Klenow (2016) have employed the same welfare criterion in their study on welfare differences across countries, highlighting the role of uncertainty and life expectancy differences compared to differences in material consumption.

[3]*Ex post*, like for all redistributive measures, there may be distributional conflicts after the uncertainty is resolved, which is not our focus in this paper.

[4]See www.who.int and www.health-inequalities.eu/. According to the WHO, health inequality is defined as "differences in health status or in the distribution of health determinants between different population groups". See Chetty et al. (2016) for a recent study documenting health inequality in the U.S. Similar socioeconomic gradients are observable in Europe, including Germany, albeit at a somewhat lower level (Kunst et al., 2005; Harttgen et al., 2013).

[5]Modern gerontology tries to explain human ageing by employing basic insights and mechanisms from reliability theory, which describes the human organism as a complex, redundant system (Gavrilov and Gavrilova, 1991). The notion of ageing as accelerated loss of organ reserve is in line with the mainstream view in the medical science. For example, initially, as a young adult, the functional capacity of human organs is estimated to be tenfold higher than needed for survival (Fries, 1980).

[6]Dalgaard and Strulik (2014) integrated into life cycle economics the notion of health deficit accumulation to understand the association between income and longevity. The model has also been applied, *inter alia*, to examine the education gradient in health and life expectancy (Strulik, 2013) and the long-run evolution of retirement behavior (Dalgaard and Strulik, 2012).

interactions of health spending and endogenous longevity with the pension system, and its implications for health inequality.

We distinguish health care expenses for the working-aged from health expenditure targeted to typical illnesses of the elderly. Examples of the former would be expenses for mass examinations of the health status of pupils at schools, costs for educational health campaigns (about nutrition, usage of soft drugs, prevention of HIV infections etc.), and expenses for treating health problems and curing illnesses which typically also hit younger adults, like type 1 diabetes, virus infections, bacterial infections, orthopedic issues after accidents, psychiatric problems. Examples of expenses affecting the distribution of health deficits of retirees conditional on the distribution of health deficits of the working-aged are those treating cardiovascular diseases, type 2 diabetes, cancer, stroke, lung disease, and arthrosis. We measure health inequality of workers and retirees separately by the Gini coefficient of these distributions. The model ingredient to capture stochastic path-dependency in the evolution of individual health deficits implies that health expenditures targeted to the working-aged affect the distribution of health deficits not only in this group but also among retirees. Consequently, improving health of the working-aged raises life expectancy for individuals at retirement age and *ceteris paribus* reduces pension benefits. It also raises the productivity of workers and their contributions to the social insurance system, with positive effects on pension benefits. Taking into account both effects together with the effects of health spending for the elderly means that a quantitative approach is needed to disambiguate the analytical considerations.

The main assumption that keeps the analysis tractable and the numerical results well interpretable is that workers fully rely on the public (PAYG) pension system to finance old-age consumption. A prime candidate for examining the optimal design of a social insurance system in such a context is Germany, where private old age savings quantitatively play a minor role.[7] Retired households received about 80 percent of income from social security in the 1990s (Börsch-Supan and Schnabel, 1998). Empirical evidence also suggests that

[7] That said, the scope of our study certainly extends to other advanced countries. For instance, in the US, social security is the most important source of support of retirees for the bottom half of the income distribution (Poterba, 2014). Financial assets outside retirement accounts play a minor role for the vast majority of households.

assuming agents who do not adjust private savings when public pension policy changes well describes the behavior of the vast majority of individuals (Chetty, 2015). For instance, in the year 2002, in Germany a subsidized private annuity market scheme started operating that was similar to the subsidized IRA accounts in the US. The public subsidies in this so-called "*Riester*-scheme" are especially high as a percentage of contributions for low income households with children. They were accompanied by heavy marketing campaigns of the federal government and insurance companies. Moreover, there was a wide discussion of demographic changes and the implications on the public pension system in the media. Indeed, about 11 million contracts have been signed until the end of March 2008. Nevertheless, the impact of the subsidies on savings in private annuity market was negligible (Corneo, Keese and Schröder, 2009; Börsch-Supan et al., 2015). This suggests that the saving volumes defined in the contracts are low and/or have replaced other forms of private annuity savings (that had already low volumes for the bulk of households to begin with).

We also focus on a public health insurance system. Again, in Germany, private insurance for health purposes plays a relatively minor role. Only top earners, civil servants and self-employed may opt out of the public PAYG health system. Consequently, 90 percent of employees in Germany were publicly health-insured in the year 2011 (Statistisches Bundesamt, 2015). In any case, the macroeconomic links between health spending and pension benefits highlighted in our analysis would be similar in a mandatory private insurance system (e.g. like in Switzerland).

The main results from our numerical analysis may be summarized as follows. First, the *status quo* health system in Germany is approximately optimal. Second, the possibility to prolong life via *future* medical progress shall be exploited by increasing the health contribution rate − and drastically so in some cases. Third, to limit the increase in the total tax burden when the health contribution rate is raised, it is optimal to lower the pensions savings rate and increase the retirement age. In most cases, it is optimal though to increase the retirement age by a smaller factor than life expectancy expands. Fourth, more health spending as an optimal response to a more powerful medical technology, as a rule, leads to more health inequality. The reason is that there are disproportionately large gains in life expectancy for those who develop only a small number of health deficits to begin with.

After reviewing the related literature in section 2, we develop in section 3 a theoretical model based on evidence from gerontology. It highlights the fundamental interactions between public pensions and health spending targeted to working-aged individuals and retirees. Section 4 calibrates our framework to Germany, which has a public pay-as-you-go (PAYG) system for both health care and pensions. Section 5 conducts numerical analysis to derive the currently optimal joint design of health and pension policy behind the veil of ignorance and studies the implications of the suggested policy reform on health, life expectancy, and health inequality. Section 6 examines how the optimal policy design should adjust when medical technology further improves and what it implies. The last section concludes.

2 Related Literature

In order to measure human functionality the medical science has proposed several indices of human capability or disability. The theory and calibration approach in the present paper is based on the so-called *frailty index*, which is particularly related to reliability theory (Gavrilov and Gavrilova, 1991).[8] The frailty index is computed for a large sample of individuals and gives the fraction of the bodily impairments which are actually present out of a long list of potential impairments, ranging from mild deficits (reduced vision, incontinence) to near lethal ones (e.g. stroke). The evidence suggests that the frailty index of an individual correlates exponentially with age, that at any given age the number of deficits in a given population is approximately Poisson-distributed, and that the probability of death strongly depends on the number of health deficits that one has accumulated over time (e.g. Mitnitski and Rockwood, 2002a, 2002b, 2005). Associating health status with a simple count measure of health deficits is thus both appealingly simple and empirically successful. According to Rockwood and Mitnitski (2007) and Searle et al. (2008), the exact choice of the set of potential deficits is not crucial, provided that the set is sufficiently large.

Another important insight from gerontology for the present paper is that individual

[8] Strulik and Vollmer (2013) used the reliability approach of Gavrilov and Gavrilova (1991) to empirically investigate its implications for long-run trends of human ageing and longevity.

deficit accumulation is path-dependent. Transitions in health status can be very accurately described by a Markov-chain augmented Poisson law according to which the probability to get another health deficit next period depends positively on the number of already accumulated health deficits (Mitnitski et al., 2006, 2007a, 2007b). This fact makes the simultaneous investigation of health and pension policy interesting and challenging.

Notwithstanding the advances in the natural sciences to understand life cycle health, the common conceptualization of health in economics is still based on the Grossman (1972) model.[9] The basic idea in that approach is that individuals accumulate health through investment in health capital, similar to the accumulation of human capital through investment in education. Without further amendments this means that desired health expenditure drops at the point of retirement and that health depreciation is greater when the stock of health is large, that is when individuals are relatively young and healthy. Preserving health would thus require health expenditure to be high at working age and low at old age (for a critique, see Case and Deaton, 2005). In order to counteract this problem, the literature has assumed that the health depreciation rate is increasing with age. In contrast, modern gerontology suggests that individuals, as they age, do not accumulate health capital but health deficits. This difference matters particularly in quantitative analysis based on a calibrated model,[10] like in the present paper where we integrate physiological ageing into a novel equilibrium framework with two tiers of the social insurance system and endogenous longevity. The approach enables us to calibrate the health technology based on observables from modern gerontology research.

There exists a relatively large literature discussing the impact of social security on labor supply and retirement and on the optimality or sustainability of public pension systems (e.g. Auerbach and Kotlikoff, 1987; Imrohoroglu, Imrohoroglu and Joines, 1995; Börsch-Supan, 2000; Jaag, Keuschnigg and Keuschnigg, 2010, 2011; see Liebman and Feldstein, 2002, for a survey). Particularly related to our paper is the study by Conesa and Krueger (1999) who like us study welfare effects of social security reform for an economy in which heterogenous

[9]The basic framework of Grossman (1972) has been extended in various directions (e.g. Ehrlich and Chuma, 1990; Hall and Jones, 2007).

[10]For further discussion on the difference between the accumulation of health capital and health deficits, see Dalgaard and Strulik (2014).

individuals face *a priori* uncertainty about their ability (productivity). The interaction of pension finance and health care, however, is not investigated. Sinn (1995) showed that income redistribution is desirable by increasing risk-taking of expected utility maximizing individuals behind the veil of ignorance, i.e. before idiosyncratic ability is revealed. Conesa, Kitao and Krueger (2009) have used this concept in a macro model with idiosyncratic ability of workers and a social security system. The focus of their study, however, was not on optimal social security provision but on optimal income taxation.

While most of the conventional public pension literature ignores issues of health and longevity, there exists a smaller literature investigating the impact of health on labor supply and retirement (Wolfe, 1985; Philipson and Becker, 1998; French, 2005; Heijdra and Romp, 2009; French and Jones, 2011; Imrohoroglu and Kital, 2012; Bloom, Canning and Moore, 2014). In Wolfe (1985), health is endogenously accumulated but retirement is not determined by welfare maximization. Philipson and Becker (1998) investigate a life cycle model with given retirement age, longevity enhancing health expenditure, and (public) annuities. They argue that retired individuals demand too much health care because they do not take into account the effect of their longevity increasing behavior on the annuity level. They thus decide to live inefficiently long rather than to live well. Heijdra and Romp (2009) analyze the impact from pension reform in a general equilibrium setting, in the presence of a realistic – but exogenously given – mortality process. Bloom, Canning and Moore (2014) develop a life cycle model and use it to gauge the impact of changes in income and life expectancy on age of retirement. Calibration to the US suggests that the optimal retirement age decreases because of an income effect when wages grow despite increases in longevity. Health and longevity, however, are exogenously given.

Pestieau, Ponthière and Sato (2008) argue that private health spending should be taxed when the replacement rate is sufficiently large. Leroux, Pestieau and Ponthière (2011a,b) extend the model towards heterogenous agents who differ in their (genetically determined) probability of survival to retirement age. They show that optimal redistribution goes from high-productivity to low-productivity agents and from short-lived to long-lived individuals. Kuhn and Prettner (2016) study the impact of an increasing labor intensive health care sector on labor productivity, welfare, and growth in an overlapping generations context.

While the available studies point to various interesting interactions of health and public policy they abstract from important other channels. Most importantly the available literature focussed on the probability to reach an exogenously given retirement age and abstract from the effect of health on longevity, i.e. the years spent in retirement. The available literature also did not take into account that idiosyncratic health endowments and health care during the working age of the population affects productivity and income and therewith the desired age of retirement. In particular, the path-dependency of health in working age and health in old age, emphasized in the gerontological literature, remained unexplored. In this paper, we aim to overcome these shortcomings. We also attempt to fill an important gap in the existing literature by addressing the questions how health spending should be allocated over the life-cycle in interaction with the pension system and how health expenditure affects health inequality.

3 The Model

Consider the following continuous-time model. At each date t, a new cohort of *ex ante* identical individuals is born. The cohort size is time-invariant and normalized to unity. This assumption reflects our focus on the effects of ageing on the social insurance system caused by higher life expectancy rather than by (presumably temporary) changes in the birth rate. Ageing is stochastic in the sense that the individual deterioration process of health, and thus life-time, is stochastic. Life consists of a working period and a retirement period.

3.1 The Social Insurance System

The length of the working period is denoted by $\bar{R}$ and the same for all individuals, for simplicity. It may be thought of the statutory retirement age. The government provides a health care system and a pension system to maximize *ex ante* welfare behind the veil of ignorance. Like in Germany, health expenditure and pension benefits are financed by proportional social insurance contributions levied on labor income. There are separate budgets with contribution rates $\tau_h \in (0,1)$ and $\tau_s \in (0,1)$, respectively. Both systems are pay-as-you-go (PAYG), i.e. the revenues are paid out contemporaneously and the budgets are balanced. We distinguish between health spending targeted to the working-aged population (e.g. for prevention programmes and curative care for illnesses that typically also hit younger adults, like virus infections and psychiatric problems) and health spending targeted to retirees (e.g. for treating illnesses typically related to old age, like cardiovascular diseases, cancer and arthrosis). The pension system is such that relative contributions between individuals of the same cohort to the system during the working period correspond to relative benefits during retirement in each point of time. Pension benefits are time-invariant for an individual during the retirement period. There are no frictions in the system and pension income is not used to finance the social insurance system.

In addition, the government levies a co-linear tax on labor income. The tax schedule reads as $\tau_w I - \mathcal{T}$, where I is labor income, τ_w is the marginal tax rate and $\mathcal{T}$ is referred to as "transfer" (i.e. an earned income tax credit). As will become apparent, individuals with lower health status will supply less labor. Assuming a balanced budget, labor income taxation is therefore redistributive.

We abstract from private forms of health expenditure and pension insurance. Specifically, a private annuity market is missing and individuals cannot save privately for the retirement period. This captures, albeit in a pronounced way, the little importance of private savings for retirement wealth for the vast majority of households in Germany (Börsch-Supan and Schnabel, 1998) for which we calibrate our model. The public pension system ('social security') is an important source of retirees' income in the US as well (Poterba, 2014). Allowing for private pension savings to complement social security would enhance complexity to the point of intractability and would probably undermine credibility and interpretability of our results. Assuming non-optimizing households with respect to old-age consumption is consistent with evidence from behavioral economics showing that most individuals stick to default pension plans offered by their employers (e.g. Chetty, 2015).[11] Such evidence

[11] In an interesting recent paper, Caliendo and Findley (2013) derive the optimal social security provision in the US by analyzing a calibrated model in which individuals save an exogenous fraction of their disposable income. Under such non-optimizing behavior, the current size of the US social security program is supported.

widely opens the scope for public policy, as discussed by Beshears et al. (2009), who survey the literature. *Inter alia* they point to evidence by Cronqvist and Thaler (2004) who show that the rate of return of the default portfolio in the Swedish social security system was higher than the performance of individuals who opted out of the default and selected the portfolio of assets by themselves.

3.2 Production

At each date, there is a single homogenous consumption good which is produced according to a neoclassical, constant-returns-to-scale production technology. Output Y is given by

$$Y = F(K, AL) \equiv ALf(k), \quad k \equiv \frac{K}{AL}, \tag{1}$$

where K and L are the inputs of physical capital and labor, the latter being measured in efficiency units. A is an exogenous measure of productivity. $f(\cdot)$ is strictly increasing, strictly concave, and fulfills the Inada conditions.

Output is sold in a perfectly competitive environment. The output price is normalized to unity. The rate of return to capital, r, is internationally given (i.e. we consider a small open economy assuming capital income is not taxed) and time-invariant. Thus, profit maximization of the representative firm implies that k is given by $r = f'(k)$, i.e. $k = (f')^{-1}(r) \equiv \bar{k}(r)$. Consequently, the wage rate per efficiency unit of human capital reads as $w = A\omega$ with $\omega \equiv f(\bar{k}(r)) - \bar{k}(r)f'(\bar{k}(r))$.

3.3 Individuals

Individuals are indexed by i. The individual number of health deficits during the working period and the retirement period is denoted by $n_1(i)$ and $n_2(i)$, respectively. An individual reaches the retirement age if he/she has sufficiently few health deficits in the working period. Let $\tilde{T}(n)$, $n \in S = \{0, 1, ..., \bar{n}\}$, be a strictly decreasing function with the following interpretation. Individual i reaches the retirement age if $\tilde{T}(n_1(i)) \geq \bar{R}$ and dies before age $\bar{R}$ otherwise; in the latter case, life-time is given by $\tilde{T}(n_1(i))$. If i reaches retirement age, life-time is $\max(\bar{R}, \tilde{T}(n_2(i)))$. Let $\bar{S} \equiv \{n \in S : n > \tilde{T}^{-1}(\bar{R})\}$ denote the set of health deficit numbers in working age such that an individual does not reach the retirement age and $\underline{S} \equiv \{n \in S : n \leq \tilde{T}^{-1}(\bar{R})\}$ the set of health deficits that it does; $S = \underline{S} \cup \bar{S}$. In sum, individual life-time, $T(i)$, negatively depends on the number of individual health deficits (Mitnitski et al., 2005, 2007) and is given by[12]

$$T(i) = \begin{cases} \tilde{T}(n_1(i)) \text{ if } n_1(i) \in \bar{S}, \\ \bar{R} \text{ if } n_1(i) \in \underline{S} \text{ and } n_2(i) \in \bar{S}, \\ \tilde{T}(n_2(i)) \text{ otherwise.} \end{cases} \quad (2)$$

Life-time is finite even without any health deficits during retirement. The healthiest retiree dies at age $T_{\max} \equiv \tilde{T}(0) < \infty$. The individual length of the working period, $R(i)$, is given by

$$R(i) = \tilde{R}(n_1(i), \bar{R}) \equiv \begin{cases} \tilde{T}(n_1(i)) \text{ if } n_1(i) \in \bar{S}, \\ \bar{R} \text{ if } n_1(i) \in \underline{S}. \end{cases} \quad (3)$$

Individuals derive utility from material consumption and higher disutility from both higher labor supply in the working period and an increased length of the working period. Life-time utility of an individual i reads as

$$U(i) = \int_0^{T(i)} e^{-\rho t} \left(\frac{c(i,t)^{1-\sigma} - 1}{1-\sigma} - \kappa(n_1(i)) \frac{l(i,t)^{1+1/\eta}}{1+1/\eta} \right) \mathrm{d}t - V(R(i), n_1(i)), \quad (4)$$

where t indexes calendar time, $c(i,t)$ and $l(i,t)$ are consumption and labor supply of individual i at time t, respectively, $\rho \in (0,1]$ is the discount rate, $\sigma > 0$ is the degree of relative risk aversion, and $\eta > 0$ is the Frisch elasticity of labor supply (at the intensive margin). Function $\kappa(n)$ is non-decreasing and captures that a worse health status may raise the disutility of labor. V represents the disutility from working along the extensive margin, also possibly dependent on health deficits at working age. $V(R, n_1)$ is increasing and convex

[12]The two-period set up in continuous time may imply that a non-zero mass of individuals dies exactly at statutory retirement age $\bar{R}$. According to (2), an individual surviving to retirement age may experience a health shock and immediately die after reaching the statutory retirement age. In the numerical analysis, reasonably, the mass of individuals dying exactly at age $\bar{R}$ will be negligible.

as a function of the length of the working period, R, and non-decreasing in the number of health deficits during the working period, n_1. Also suppose that V has weakly increasing differences, i.e., if anything, a marginal increase in the length of the working period has a larger impact on the disutility of work when the worker is less healthy; formally, we assume that $V(R, n_1') - V(R, n_1)$ is non-decreasing in R whenever $n_1' > n_1$.[13]

According to (2)-(4), health deficits during retirement affect utility only via reducing life expectancy. We deliberately focus on this case to obtain a conservative value for the welfare-maximizing level of health spending. If we find that the status quo health spending is not too high even in the case where health status has no non-material effect on utility for the elderly, as assumed also in Becker (2007), then there is a strong argument not to currently decrease health spending and possibly to increase it drastically if medical technology improves.

We focus our analysis on a steady state equilibrium where the composition of cohorts is the same at each point in time. Each individual possesses the same amount of financial assets during working age, $\mathfrak{a}$.[14] Thus, including the government transfer, $\mathcal{T}$, they have non-labor income $y = r\mathfrak{a} + \mathcal{T} \equiv \tilde{y}(\mathcal{T})$. We impose the standard assumption that the interest rate equals the discount rate, $r = \rho$. Since individuals rely on the pension system for old age consumption, consequently, they are perfectly smoothing consumption during the working period, i.e., for all $t \in [0, R(i)]$,

$$c(i,t) = (1 - \tau_w - \tau_h - \tau_s)wl(i,t) + y \equiv \tilde{w}(\tau)l(i,t) + \tilde{y}(\mathcal{T}), \tag{5}$$

where $\tilde{w}(\tau) \equiv (1 - \tau_w - \tau_h - \tau_s)w$ denotes the net wage rate and $\tau \equiv (\tau_h, \tau_s, \tau_w)$. The first-order condition on labor supply implies that at each instant the marginal rate of substitution between consumption and labor supply equals the net wage rate. Hence, using (5), labor

[13] Under differentiability, the assumption of weakly increasing differences of disutility function V means that $V_{nR} \geq 0$, where subscripts on V denote partial derivatives.

[14] Those are introduced in order to improve the calibration in section 4, foremost of the Frisch elasticity of labor supply, η. We implictly assume that financial wealth is passed on from parents to children when entering retirement. Working aged individuals reach the retirement age with high probability and the size of the working aged population remains approximately constant also when considering health policy changes in our analysis.

supply of individual i is implicitly given by the condition

$$\frac{\kappa(n_1(i))l(i,t)^{1/\eta}}{[\tilde{w}(\tau)l(i,t)+\tilde{y}(\mathcal{T})]^{-\sigma}} = \tilde{w}(\tau). \tag{6}$$

For all $t \in [0, R(i)]$, individual labor supply can thus be expressed as a function of health deficits at working age, n_1, the net wage rate $\tilde{w}$, and non-labor income $\tilde{y}$:

$$l(i,t) = \tilde{l}(n_1(i), \tilde{w}(\tau), \tilde{y}(\mathcal{T})). \tag{7}$$

Labor supply is lower for individuals with more health deficits if and only if $\kappa' > 0$. The case where $\partial\tilde{l}(n_1,\cdot)/\partial n_1 < 0$ is consistent with evidence provided by Cai, Mavromaras and Oguzoglu (2014), showing that individuals who experience moderate health shocks respond by incremental reductions in labor supply. Labor supply is increasing in non-labor income, $\partial\tilde{l}(n_1,\tilde{w},\tilde{y})/\partial\tilde{y} > 0$. We will calibrate the model such that also $\partial\tilde{l}(n_1,\tilde{w},\tilde{y})/\partial\tilde{w} > 0$ holds, i.e. labor supply is strictly decreasing in social insurance contribution rates τ_h and τ_s.

According to (5) and (7), consumption of individual i during the working period reads, for all $t \in [0, R(i)]$, as

$$c(i,t) = \tilde{w}(\tau)\tilde{l}(n_1(i), \tilde{w}(\tau), \tilde{y}(\mathcal{T})) + \tilde{y}(\mathcal{T}) \equiv \tilde{C}_1(n_1(i), \tau, \mathcal{T}). \tag{8}$$

3.4 Distribution and Evolution of Health Deficits

Health spending is measured in terms of the numeraire good. Health spending levels targeted to the working-aged and retirees per capita of the respective group are denoted by $\mathfrak{h}_1$ and $\mathfrak{h}_2$, respectively. In line with empirical evidence, the number of health deficits in the population both at working age and at retirement age is Poisson-distributed in both periods of life. Let

$$g(n_j, \lambda_j) = e^{-\lambda_j}\frac{(\lambda_j)^{n_j}}{n_j!} \tag{9}$$

denote the probability density function (p.d.f.) of health deficits in period $j \in \{1, 2\}$ of life. The Poisson parameters λ_1 and λ_2 (the average number and variance of health deficits in period 1 and 2, respectively) depend on productivity-adjusted per capita health spending levels $h_1 \equiv \mathfrak{h}_1/A$ and $h_2 \equiv \mathfrak{h}_2/A$ in period 1 and 2, respectively. That is, to maintain the amount of health services after an increase in total factor productivity, A, health spending has to increase proportionally with A.[15] We assume that

$$\lambda_1 = \tilde{a}_1(h_1), \tag{10}$$

$$\lambda_2 = \tilde{a}_2(h_2) + bn_1, \tag{11}$$

where $\tilde{a}_1$ and $\tilde{a}_2$ are functions with properties $\tilde{a}_j' < 0$ and $\tilde{a}_j'' > 0$, $j \in \{1, 2\}$. The convexity assumptions capture the notion that the negative effect of higher health expenditure on health deficits is strictly decreasing. $b > 0$ is a parameter that is independent of health spending. It captures that the number of health deficits in retirement age, n_2, is path-dependent in a stochastic sense. That is, the distribution of n_2 is conditional on n_1. The path-dependency of health deficits is consistent with overwhelming evidence from gerontology which suggests that the probability to get another health deficit next period depends positively on the number of already accumulated health deficits, according to a Markov-chain augmented Poisson law (Mitnitski et al., 2006, 2007a, 2007b). Using (10) and (11) in (9), the joint p.d.f. of (n_1, n_2) is given by

$$G(n_1, n_2, h_1, h_2) \equiv g(n_1, \tilde{a}_1(h_1))g(n_2, \tilde{a}_2(h_2) + bn_1). \tag{12}$$

According to (2) and (9)-(12), life expectancy at birth (LE) is increasing in health spending and reads as

$$\begin{aligned} \text{LE} \equiv \sum_{n_1 \in \bar{S}} g(n_1, \tilde{a}_1(h_1))\tilde{T}(n_1) + \bar{R} \sum_{n_1 \in \underline{S}} \sum_{n_2 \in \bar{S}} G(n_1, n_2, h_1, h_2) + \\ \sum_{n_1 \in \underline{S}} \sum_{n_2 \in \underline{S}} G(n_1, n_2, h_1, h_2)\tilde{T}(n_2). \end{aligned} \tag{13}$$

Denote by N_1 and N_2 the size of the population in working age and the number of

[15] For instance, suppose productivity advances in the final goods sector do not improve average health status since the health sector employs labor as input and wage costs rise proportionally (recall that the wage rate w is proportional to A). For simplicity, we implicitly assume that health workers are cross-border commuters.

retirees, respectively. Summing the survivors in working age over all cohorts, the number of workers reads as

$$N_1 = \sum_{n_1 \in S} g(n_1, \tilde{a}_1(h_1))\tilde{R}(n_1, \bar{R}) \equiv \tilde{N}_1(h_1, \bar{R}). \tag{14}$$

It is easy to see that $\tilde{N}_1$ is non-decreasing in h_1 and increasing $\bar{R}$. If all individuals reach the retirement age ($\bar{S} = \varnothing$), then $N_1 = \bar{R}$. Using (12), the number of retirees, N_2, can be written as

$$N_2 = \sum_{n_1 \in \underline{S}} \sum_{n_2 \in \underline{S}} G(n_1, n_2, h_1, h_2) \left(\tilde{T}(n_2) - \bar{R}\right) \equiv \tilde{N}_2(h_1, h_2, \bar{R}). \tag{15}$$

Because lowering the number of health deficits raises life-time and because health deficits are path-dependent, $\tilde{N}_2$ is increasing in both h_1 and h_2. $\tilde{N}_2$ is decreasing in $\bar{R}$.

3.5 Government Budget Constraints

The government budget constraints reflect the macroeconomic trade-offs faced by the social planner and are derived next.

3.5.1 Health Expenditure Constraint

Using (8), the government budget constraint for health spending (financed by labor income contributions at rate τ_h) is given by $N_1\mathfrak{h}_1 + N_2\mathfrak{h}_2 = \tau_h wL$, where total labor input is

$$L = \sum_{n_1 \in S} g(n_1, \tilde{a}_1(h_1))\tilde{R}(n_1, \bar{R})\tilde{l}(n_1, \tilde{w}(\tau), \tilde{y}(\mathcal{T})) \equiv \tilde{L}(h_1, \tau, \bar{R}, \mathcal{T}). \tag{16}$$

Using (14), (15), $h_1 = \mathfrak{h}_1/A$, $h_2 = \mathfrak{h}_2/A$, $w = A\omega$ and (16), we obtain

$$\tilde{N}_1(h_1, \bar{R})h_1 + \tilde{N}_2(h_1, h_2, \bar{R})h_2 = \tau_h \omega \tilde{L}(h_1, \tau, \bar{R}, \mathcal{T}). \tag{17}$$

According to (17), there is a non-trivial relationship between health spending for the working-aged and for retirees. First, for a given tax revenue ($\tau_h wL$), there is a trade-off between the two since both kinds of spending are financed by the same source. Second, if h_1 rises, the distribution of health deficits in the working-aged population improves. If anything, this has positive effects on total labor supply ($\partial \tilde{L}/\partial h_1 > 0$) such that the health budget available per retiree is enlarged. If $\bar{S} \neq \varnothing$ (i.e. not all individuals reach the retirement age) and h_1 increases, more individuals survive to the retirement period. Moreover, if health status correlates with labor supply ($\kappa' > 0$), workers supply more labor at each instant. Third, however, an increase in h_1 means that the population size of retirees, N_2, increases via the path dependency of health deficits (if $\bar{S} \neq \varnothing$, also N_1 increases) leaving less health spending per retiree.

In the case where the (net) wage elasticity of labor supply is positive, individuals reduce labor supply in response to a higher pension savings rate, τ_s. Thus, $\partial \tilde{L}/\partial \tau_s < 0$ and revenue in the health system decreases. Finally, a reasonable policy mix would avoid Laffer effects, such that the health budget shall be enlarged by an increase in the health contribution rate τ_h.

3.5.2 Pension Payment Constraint

We next discuss the pension system. Consider first the properties of the "dependency-ratio", defined as the number of beneficiaries per worker,

$$D = \frac{N_2}{N_1} = \frac{\tilde{N}_2(h_1, h_2, \bar{R})}{\tilde{N}_1(h_1, \bar{R})} \equiv \tilde{D}(h_1, h_2, \bar{R}). \tag{18}$$

Lemma 1. *The dependency ratio function, $\tilde{D}$, is increasing in health spending targeted to the elderly, h_2, and decreasing in the statutory retirement age, $\bar{R}$. The impact of an increase in h_1 on $\tilde{D}$ is generally ambiguous; it is positive if all individuals reach the retirement age ($\bar{S} = \varnothing$).*

Proof. Follows from (18) in view of the properties $\partial \tilde{N}_1/\partial h_1 \geq 0$ (with equality if $\bar{S} = \varnothing$), $\partial \tilde{N}_1/\partial \bar{R} > 0$, $\partial \tilde{N}_2/\partial \bar{R} < 0$, $\partial \tilde{N}_2/\partial h_1 > 0$, and $\partial \tilde{N}_2/\partial h_2 > 0$. ■

Lemma 1 suggests that higher health spending for the elderly has a dismal effect on pension benefits, by raising life expectancy and thus also the dependency ratio. Because of the stochastic path-dependency of health deficits, the same may hold when increasing health spending for the working-aged. The effect is generally ambiguous though because an increase in h_1 may help more people to survive until $\bar{R}$.

Recall that the government perfectly smoothes consumption during the retirement period by paying out an individual-specific and time-invariant pension income, denoted by $C_2(i)$ for individual i. The ratio of pension benefits of two individuals who reach the retirement period is equal to the ratio of their labor income. Thus, for two individuals i and i',

$$\frac{C_2(i)}{C_2(i')} = \frac{\tilde{l}(n_1(i), \tilde{w}, \tilde{y})}{\tilde{l}(n_1(i'), \tilde{w}, \tilde{y})}. \tag{19}$$

Denote by $C_2^{\max}$ the pension benefit for a retiree who had no health deficits during the working period and thus supplied $\tilde{l}(0, \tilde{w}, \tilde{y})$ units of labor. According to (19), for any i we have

$$C_2(i) = \tilde{l}(n_1(i), \tilde{w}, \tilde{y}) \frac{C_2^{\max}}{\tilde{l}(0, \tilde{w}, \tilde{y})}. \tag{20}$$

In a PAYG pension system, the total revenue from the pension contributions, $\tau_s wL$, must equal the aggregate expenses. Thus, using (20),

$$\tau_s wL = \sum_{n_1' \in \underline{S}} \sum_{n_2' \in \underline{S}} G(n_1', n_2', h_1, h_2) \left[\tilde{T}(n_2') - \bar{R}\right] \tilde{l}(n_1', \tilde{w}, \tilde{y}) \frac{C_2^{\max}}{\tilde{l}(0, \tilde{w}, \tilde{y})}. \tag{21}$$

Solving (21) for $C_2^{\max}/\tilde{l}(0, \cdot)$, inserting into (20) and using $\lambda_1 = \tilde{a}_1(h_1)$ as well as (16) implies that consumption of beneficiary i for all $t \in [\bar{R}, T(i)]$ is given by

$$\begin{aligned} c(i,t) = C_2(i) = \tilde{l}(n_1(i)) &\frac{\tau_s w \sum_{n_1' \in S_1} g(n_1', \tilde{a}_1(h_1)) \tilde{R}(n_1', \bar{R}) \tilde{l}(n_1', \tilde{w}(\tau), \tilde{y}(\mathcal{T}))}{\sum_{n_1' \in \underline{S}} \sum_{n_2' \in \underline{S}} G(n_1', n_2', h_1, h_2) \left[\tilde{T}(n_2') - \bar{R}\right] \tilde{l}(n_1', \tilde{w}(\tau), \tilde{y}(\mathcal{T}))} \\ &\equiv \tilde{C}_2(n_1(i), h_1, h_2, \tau, \bar{R}, \mathcal{T}),\; n_1(i) \in \underline{S}. \end{aligned} \tag{22}$$

Proposition 1. *The PAYG pension benefit function $\tilde{C}_2$ is increasing in the statutory retirement age, $\bar{R}$. If and only if the wage elasticity of labor supply is zero, $\tilde{C}_2$ is independent of the health contribution rate, τ_h. $\tilde{C}_2$ is decreasing in health spending targeted to retirees, h_2. The effect of an increase in health spending targeted to the working-aged, h_1, on $\tilde{C}_2$ is generally ambiguous; it is negative if $\kappa' = 0$ and $\bar{S} = \varnothing$.*

Proof. Follows from (22) in view of $\tilde{a}_1' < 0$, $\tilde{a}_2' < 0$, and (3). ■

An increase in the statutory retirement age, $\bar{R}$, raises pension benefits by decreasing the dependency ratio, all other things being equal. Moreover, if labor supply is elastic, pension benefits are affected by the health contribution rate, τ_h. The result reflects the interaction between the two pillars of the social insurance system through the distortionary effect of taxation. The interaction between health spending and pension finance is also seen when we change old-age health care spending, h_2. An increase in h_2 raises life expectancy and thus lowers pension benefits per retiree. By contrast, an increase in health care spending for workers, h_1, may as well boost pension benefits. It raises labor supply if $\kappa' > 0$ and helps that fewer individuals die before they reach retirement age (if $\bar{S} \neq \varnothing$). Both effects increase the contributions to the pension system. However, these positive effects do not necessarily dominate the effect originating from the path-dependency of health deficits: as the average number of health deficits prior to retirement is reduced by raising h_1, life expectancy at retirement age increases, in turn raising the dependency ratio.

3.5.3 Transfer Income

Transfer expenditure for working-aged individuals must equal the revenue from taxing labor income at rate τ_w, i.e., $N_1\mathcal{T} = \tau_w wL$. Using (14) and (16), the transfer $\mathcal{T} \equiv \tilde{\mathcal{T}}(h_1, \tau, \bar{R})$ is implicitly given by

$$\tilde{N}_1(h_1, \bar{R})\mathcal{T} = \tau_w w\tilde{L}(h_1, \tau, \bar{R}, \mathcal{T}). \tag{23}$$

3.6 The Social Planning Problem

Our goal is to numerically derive the optimal social insurance system behind the veil of ignorance, i.e. the one that maximizes expected welfare of individuals before drawing from the distribution of health deficits early in life (and the conditional distribution later in life). Expected welfare can be derived by substituting (3), the set of deficit-dependent labor supply functions (7) as well as the expressions for first period and second period consumption levels (8) and (22) into (4) and taking expectations. The social planner then maximizes expected welfare subject to government budget constraints (17) and (23).

The social planning problem is formally stated and discussed in Appendix, highlighting the complex welfare interactions between the various policy instruments that are disambiguated in the numerical analysis. In Appendix, we also show that health spending that maximizes expected welfare also maximizes life expectancy at birth only in a special case.

4 Calibration for Germany

We calibrate our model for Germany, which separately has a public PAYG health system with a common health budget for workers and retirees,[16] a public PAYG pension system and a progressive labor income tax schedule.

We assume that the technology (1) for producing final output has the Cobb-Douglas form $Y = K^{\varrho}(AL)^{1-\varrho}$, $\varrho \in (0,1)$. For an exogenous interest rate, r, the wage rate is given by $w = A\omega$ with $\omega = (1-\varrho)(\varrho/r)^{\varrho/(1-\varrho)}$. For later reference, GDP is inferred as $Y = wL/(1-\varrho)$. Capital income is calibrated at $r\mathfrak{a} = \varrho Y$. We set the typical value $\varrho = 1/3$ for the output elasticity of capital.

We interpret a unit of calendar time in the model as 45 years. Assuming that people start on average working at age 20, the working period lasts 45 years, which is regarded as the normal earnings history in the German system (*Eck-Rentner*). In terms of our model, the current statutory retirement age in Germany is thus captured by $\bar{R} = 1$. We set the annual real interest rate and discount rate to typical values $r = \rho = 0.02$. Consistent with the construction of the frailty index in the literature, the maximum number of human health deficits is $\bar{n} = 20$. Our results are independent from the metric of health deficits as long as $\bar{n}$ is high enough.[17] According to (2), life span is a function of the accumulated health deficits. We specify $\tilde{T}(n) = T_{max} \cdot \exp(-\chi \cdot n)$, $\chi > 0$, and set the maximum life span to $T_{max} = 1.78$, which corresponds to $20 + 1.78 \cdot 45 = 100$ years.

Formally, employees and employers both contribute to the social insurance system in

[16] Our approach could also be used in the US context, which explicitly has a health budget for retirees (medicaid expenditure), by assuming that revenue is collected from taxing labor income.

[17] Our results are virtually identical when alternatively setting $\bar{n} = 30$ or $\bar{n} = 40$ (not shown). Interestingly, important statistical relations based on the frailty index are also independent of the number of potential bodily impairments as long as $\bar{n}$ is high enough; see Rockwood and Mitnitski (2007) and Searle et al. (2008).

Germany. Economically relevant is the tax incidence, however. Consistent with our small open economy assumption (i.e. perfectly elastic labor demand), we assume that all pension and health contributions are born by employees. The current pension savings rate, τ_s, is 18.7 percent according to the share of gross wages deducted for social security (*Gesetzliche Rentenversicherung*). The model assumes that there are no private savings for old age. In the case of Germany this seems to be an acceptable approximation since retired households receive about 80 percent of income from social security (see Börsch-Supan and Schnabel, 1998). The health contribution rate, τ_h, is set to 15.5 percent, which is the fraction of gross labor income paid for the German public health care insurance (*Gesetzliche Krankenversicherung*). According to the OECD (2015, Tab. 3.8), the marginal labor income tax rate in Germany for married couples with two children in the year 2014, evaluated at average income, was 26-28 percent (depending on the number of children and whether it is a one-earner or two-earner family). Without children, it was 19 percent in a two-earner family and 21 percent for single earners. We set $\tau_w = 0.25$.

In our social insurance context, we expect results to respond sensitively to the curvature of the utility function with respect to consumption, parameterized by σ. To calibrate σ, we follow Chetty (2006) and consider an individual for which *ex post* labor income and non-labor income are proportional. Using (6), it is easy to show that the uncompensated wage elasticity of labor supply is then constant and reads as

$$\left.\frac{\partial \tilde{l}(n_1, \tilde{w}, y)}{\partial \tilde{w}}\right|_{y=\varsigma \tilde{w} \tilde{l}(n_1, \tilde{w}, y)} \cdot \frac{\tilde{w}}{\tilde{l}(n_1, \tilde{w}, y)} = \frac{1+\varsigma-\sigma}{\frac{1+\varsigma}{\eta}+\sigma} \equiv \varepsilon, \tag{24}$$

$\varsigma > 0$. It depends on the Frisch wage elasticity, η, the factor of proportionality, ς, and the coefficient of relative risk aversion, σ. Expression (24) also shows that ε is positive if and only if σ is sufficiently small, which puts an upper bound on σ (Chetty, 2006); that is, $\varepsilon > 0$ if and only if $\sigma < 1 + \varsigma$. Naturally, the labor supply elasticity varies with the concept of the household. According to Bargain, Orsini and Peichl (2014), the uncompensated labor supply elasticity in Germany in the year 2001 when not distinguishing between the intensive and extensive margin is estimated to be 0.14 for men in couples and 0.31 for women in couples. For singles, it is 0.2 for men and 0.18 for women. Looking alone at the intensive margin, estimates are much lower and are basically zero for men. In the benchmark run we set ε to 0.14, the estimated labor supply elasticity for men in couples. Moreover, we assume log-utility for consumption, i.e. $\sigma = 1$, consistent with evidence by Chetty (2006), Engelhardt and Kumar (2009) and Hartley, Lanot and Walker (2013). We also follow Chetty (2006) and assume $\varsigma = 0.5$, which captures an average labor income share of two thirds. According to (24), $\varepsilon = 0.14$, $\sigma = 1$ and $\varsigma = 0.5$ imply a reasonable value $\eta = 0.58$ for the Frisch elasticity of labor supply. We provide sensitivity analysis for labor supply elasticities and the curvature of the utility function with respect to consumption.

We allow for health deficits during working age to affect labor supply by specifying $\kappa(n_1) = \kappa_0 e^{\delta n_1}$, $\kappa_0 > 0$, $\delta \geq 0$. According to (6), we then have

$$-\left.\frac{\partial \tilde{l}(n_1, \tilde{w}, y)/\partial n_1}{\tilde{l}(n_1, \tilde{w}, y)}\right|_{y=\varsigma \tilde{w} \tilde{l}(n_1, \tilde{w}, y)} = \frac{(1+\varsigma)\delta}{\frac{1+\varsigma}{\eta} + \sigma} \equiv \Xi. \tag{25}$$

This suggests that we can approximate $\tilde{l}(n_1, \cdot)/\tilde{l}(0, \cdot) \approx \exp(-\Xi n_1)$. Although empirical evidence shows that individuals with poorer health status retire earlier (Gustman and Steinmeier, 2014), Cai et al. (2014) strongly argue that individuals (presumably those who are not close to retirement age) typically respond to health shocks by gradually reducing labor supply rather than opting out fully. They present evidence on the effect of health shocks and health status at the intensive and the extensive margin. Quantitatively, the bulk of the response to health shocks is at the intensive margin, in line with our model (which ignores the extensive margin for simplicity, unless workers die before reaching the statutory retirement age). According to their Table 1, both men and women with "fair" health (the fourth out of five categories for health status) supply, on average, about 25 percent less working hours than those with "excellent" health (the highest category). Associating "excellent" health with zero health deficits and "fair" health with three health deficits suggests $\Xi \approx 0.1$.[18] With $\varsigma = 0.5$, $\sigma = 1$, $\eta = 0.58$ and $\Xi = 0.1$, (25) implies $\delta = 0.25$.

Mitnitski et al. (2007) have shown that the intergenerational distribution of deficits can

[18]For $\Xi = 0.1$, $\tilde{l}(3, \cdot)/\tilde{l}(0, \cdot) = \exp(-0.3) \approx 0.74$. For being consistent with the working hours of those with "poor" health, which are about 75% lower than of those with "excellent" health, when $\Xi = 0.1$, $\tilde{l}(n_1, \cdot)/\tilde{l}(0, \cdot) \approx 0.25$ is reached for $n_1 = 14$.

be precisely described by a Poisson process, as captured by (9). The Poisson parameters λ_1 and λ_2 which determine the arrival of new deficits in the two periods of life, are given by (10) and (11), respectively. We specify

$$\tilde{a}_j(h_j) = \alpha_j \cdot \exp(-\beta_j \cdot h_j), \ \alpha_j > 0, \ \beta_j \geq 0, \tag{26}$$

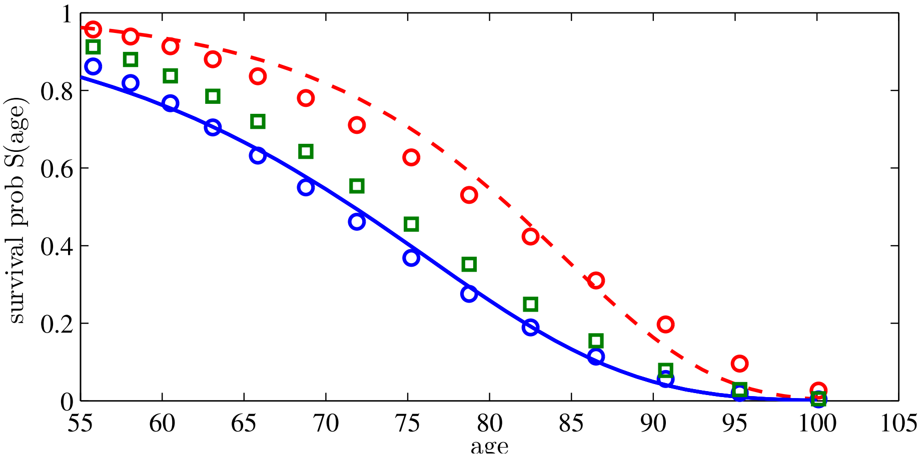
$j \in \{1, 2\}$, to capture in a parsimonious way that the arrival rates for new deficits depend on the general health environment (α_j), and a health technology with decreasing returns of health expenditure (interaction between β_j and h_j). We calibrate the parameters in (26) such that the model approximates actual survival probabilities for each age group. For that purpose we assume that health care expenditure before the 20th century was ineffective in prolonging life of adults (20 years and older), i.e. $\beta_1 = \beta_2 = 0$ for the year 1900 (and earlier). This assumption is approximately true. Before the 20th century life expectancy rose predominantly because of fewer deaths in infancy and childhood. Improving adult life expectancy is a phenomenon of the 20th century. According to Milligan and Wise (2011), mortality at age 65 did not decline substantially until the 1970s. We use the fact that for ages above 20 the force of mortality, that is the conditional probability $\mu(x)$ to die at age x, is precisely measured by *Gompertz law*, $\mu(x) = B \exp(\phi x)$. Using the data from the Human Mortality Database (www.mortality.org), Strulik and Vollmer (2013) estimate $\phi = 0.11$, $B = 0.00001$ for the year 2000 and $\phi = 0.0092$, $B = 0.00078$ for the year 1950. Unfortunately we do not have mortality data for Germany earlier than 1950. Strulik and Vollmer (2013) find that the average Western European values were $\phi = 0.08$, $B = 0.00018$ in 1900. For England and Sweden historical data exists for a longer period. The average European values in the year 1900 are approximately also observed for England in 1850-1900 and for Sweden in 1750-1900 (see Strulik and Vollmer, 2013). The time invariance of these numbers is consistent with the general observation that adult mortality was very similar in Western Europe and did not change much before the 20th century. We thus set $\phi = 0.08$ and $B = 0.00018$ for 1900 and earlier and $\phi = 0.11$ and $B = 0.00001$ for the year 2000. From these values we compute the unconditional survival probability $S(x)$ by solving $\dot{S}(x)/S(x) = \mu(x)$ for $S(x)$. The result is shown in Figure 1. The solid blue line shows survival rates in 1900, the red dashed line shows survival rates in 2000.

We begin with estimating χ, α_1, α_2, and b such that the predicted age-dependent survival probabilities provide the best fit of the actual survival probabilities in the year 1900 (given $\beta_1 = \beta_2 = 0$). The blue circles in Figure 1 show the implied survival probabilities for $\chi = 0.062$, $\alpha_1 = 1.9$, $\alpha_2 = 3.8$ and $b = 2.5$. How much of the upward shift of the survival curve during the 20th century has been caused by improved health care is a debated issue, which is not yet completely resolved. Much of the improved survival at working age was likely to be driven by improved nutrition and public health measures like sanitation and the implied reduction in the spread of diseases (McKeown, 1976; Fogel; 1994). Old age diseases like cardiovascular diseases and cancer, however, were largely unaffected by these trends and they were actually increasing during the first half of the 20th century. Moreover, the reductions in mortality at old age achieved since the 1950s can be largely attributed to medical innovations and improved medical care (Cutler and Meara, 2001). We take these stylized facts into account and assume for the benchmark run of the model that about 50 percent of improved survival of the working aged is caused by an "improved health environment", as shown by the green squares in Figure 1. It is reached by an exogenous reduction of α_1 from 1.9 to 1.5, while leaving α_2 unchanged. Notice that survival in retirement improves as well (albeit by less than 50 percent) because of the intergenerational transmission of better health as driven by path-dependency parameter b.

We assume that the remainder of the shift of the survival curve has been caused by health technology and health expenditure. To jointly calibrate technology parameters β_1, β_2, and per capita health expenditure levels, we assume that h_1 and h_2 fulfill health budget constraint (17) and $h_1/h_2 = 0.29$ is current ratio of health care expenditure per working-aged individual to that per retiree in Germany.[19] Under these assumptions, the best fit of the survival curve for the year 2000 is reached for $\beta_1 = 0.83$ and $\beta_2 = 0.60$. Predicted survival is shown by red circles in Figure 1. The calibrated model predicts that actual life

[19] We use data from the Statistical Office in Germany on health costs and population sizes split up by age, retrieved on September 20, 2015 (https://www-genesis.destatis.de/genesis/online). Total health costs for those aged 15-64 and those aged 65+ are about EUR 116 million and 123 million, respectively. The population size of those aged 65+ relative to those aged 15-64 is about 0.31. This implies that health spending for someone aged 15-64 is less than a third than health spending for someone aged 65+.

Figure 1: Actual and Predicted Survival Probability

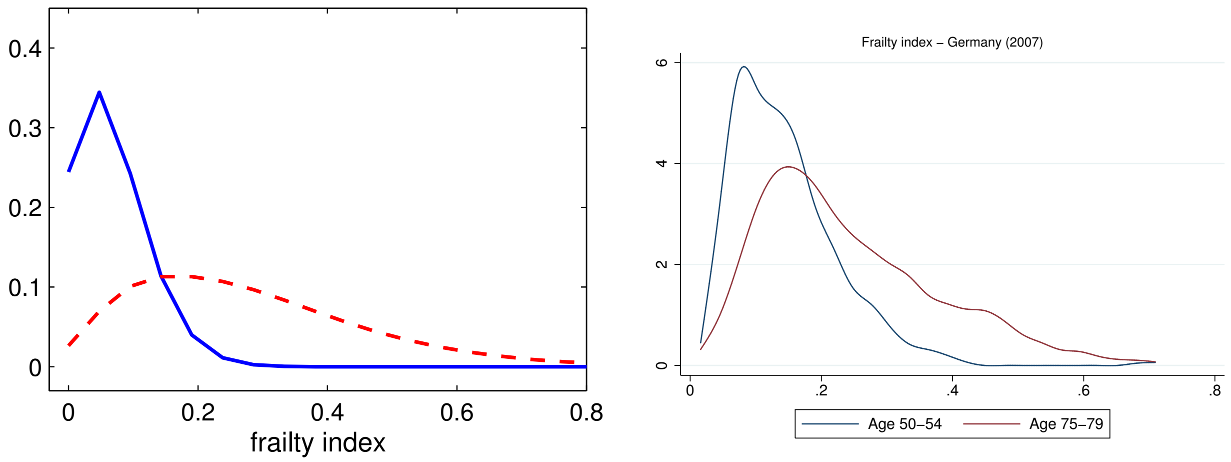


Survival probabilities in Germany according to Gompertz law in 1900 (solid line) and 2000 (dashed line) and predictions by the model (dots). Squares indicate improvement of survival not originating from improved health care. See text for details.

expectancy at birth, LE as given by (13), is 78.5 years. Actually, life expectancy at birth was 78.0 years in the year 2000 (and 80.0 years in 2010, according to World Bank, 2015). Moreover, it predicts a GDP share of health care expenditure of 10.3 percent while actually it was 10.7 percent in the year 2008.

For further comparison with the actual data we computed the implied distribution of the frailty index, i.e. of the relative number of health deficits out of a long list of potential bodily impairments, conditional on age. Harttgen et al. (2013) have calculated the frailty index from the 'Survey of Health, Ageing and Retirement in Europe' (SHARE) data for several European countries including Germany. Estimates and predictions are shown in Figure 2. As a reading example for the left panel of Figure 2, since the maximum number of health deficits in the calibrated model is $\bar{n} = 20$, a frailty index of 0.2 means four health deficits. The model approximates the overall distribution reasonably well. The working-aged individuals in our model are a bit too healthy when compared with 50-54 year old persons from the SHARE sample. This seems fine, however, since that cohort is already quite close to the retirement age compared to the average German worker. Unfortunately, SHARE does not provide any data for persons younger than 50. The frailty distribution of the retired population in our calibrated model corresponds very well to the actual frailty

Figure 2: The Frailty Index: Calibration vs. Estimation from SHARE Data for Germany



Left: predicted probability distribution of the frailty index for working age population (solid line) and retired population (dashed line). Right: Estimated density of the frailty index for the age group 50-54 and 75 to 79.

distribution of the 75-79 year olds.

Disutility of work at the extensive margin (retirement) is driven by a preference for leisure. We specify

$$V(R, n_1) = \nu \cdot (1 + \xi \cdot n_1) \cdot R^{1+1/\gamma}, \ \nu > 0, \ \gamma > 0, \ \xi \geq 0. \tag{27}$$

We set $\gamma = 0.25$, which equals the Frisch elasticity of labor supply at the extensive margin, according to recent evidence (Chetty et al., 2011a,b). It turns out that the model provides considerable variation in results with respect to alternative assumptions about ξ, i.e. the influence of health on the disutility from work. We set $\xi = 1$ in the benchmark run and provide sensitivity analysis for smaller and larger ξ. A value of ξ of one means that individuals are willing to retire three years later for an improvement of their frailty index at retirement age from 0.1 (approximately the mode of the distribution of the frailty index in Germany at age 65) to 0.05 (i.e. a reduction in health deficits from $n_1 = 2$ to $n_1 = 1$ out of $\bar{n} = 20$ potential deficits).[20]

[20]To see this, evaluate the marginal rate of substitution between R and n given utility V, i.e. $V_n/V_R = \xi R(1+\xi n_1)^{-1}/(1+1/\gamma)$, at $\xi = R = 1$, $n_1 = 2$, and $\gamma = 0.25$ (subscripts on V denote partial derivatives). This gives us $V_n/V_R = 1/15$. Recalling that a time period of one corresponds to 45 years in our model, the increase in retirement age which makes the individual indifferent between a reduction of one health deficit and working longer is $45/15 = 3$ years.

This leaves us with two degrees of freedom, the value of ν in disutility function V and the scale parameter A in the production technology. We pin down these parameters by assuming that the current social security system is constrained-optimal, i.e. that $\tau_s = 0.187$ and $\bar{R} = 1$ (retirement at 65) would be selected behind the veil of ignorance *given* the current public health system. This provides the estimates $A = 34$ and $\nu = 0.161$. An interesting question for policy analysis to which we turn now is to

5 Currently Optimal Social Insurance

In this section we determine the *jointly* optimal social security and health system behind the veil of ignorance for the current health technology in the calibrated model (future prospects are examined in section 6).

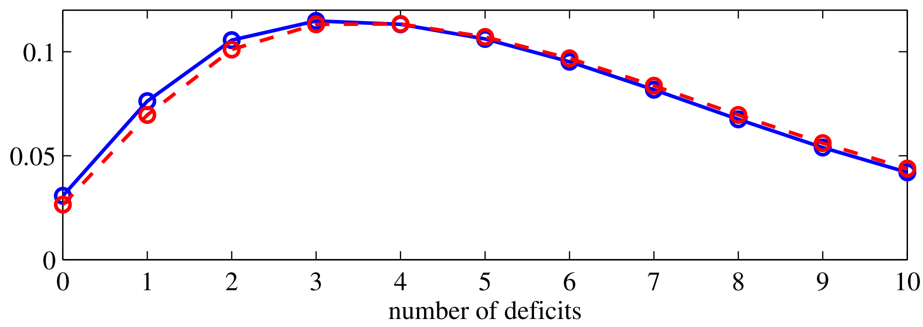
5.1 Benchmark Scenario

The first row of Table 1 displays the status quo before optimization. Results for the baseline calibration are shown in the second row ("benchmark" Case 2). The best policy is characterized by a mild increase of health expenditure as a fraction of labor income from 15.5 to 17.4 percent, i.e. by 12%. The health care improvement leads to an increase of life expectancy at birth, LE, of 0.5 years. Health spending for a younger person shall be about a fourth of the health spending for an elderly person, a mild decrease compared to the status quo. Furthermore, the optimal retirement age remains at 65 years.

Figure 3 shows the impact of switching to the optimal policy on the health deficit distribution in retirement. (Among the working population the distribution does not visibly change). For better visibility the figure focusses on the range from zero to ten deficits. The largest effect is observed for those suffering one to three health deficits. As shown in Table 1 the average health deficits stay at the status quo level for the working-aged while retired persons suffer on average from about 0.16 health deficits less.

We also computed how much the "value of life" (in monetary terms) changes after a policy reform. The value of life is typically measured as life-time welfare divided by the

Figure 3: Deficit Distribution in Retirement: Actual vs. Optimal Policy



Dashed lines: actual policy. Solid lines: optimal policy.

marginal utility of consumption. For simplicity, we refer to the rate of change in life-time welfare W as the percentage change of the value of life, $\Delta W/W$. That is, we evaluate the marginal utility of consumption at the same consumption level before and after the reform. Alternatives would not be better justified in view of the *ex post* heterogeneity of agents in our model. Going from the status quo to the benchmark case raises the value of life in a negligible fashion, $\Delta W/W \approx 0$ (not reported in Table 1). Thus, the benchmark scenario suggests that the current social insurance system in Germany is approximately optimal.

To understand how the previous numerical results depend on the baseline calibration, we now examine the effects of (not necessarily realistic) parameter changes. In order to ensure comparability with the benchmark case we re-calibrated in all subsequent cases the value of ν such retirement at age 65 remains optimal given the new parameter values and the status quo health system.

5.2 The Impact of Health on Disutility from Work

We start with varying ξ, the parameter of which we perhaps know the least. Case 3 investigates the optimal policy when health deficits do not affect the disutility from work at the extensive margin ($\xi = 0$). Naturally, health in working age plays a less important role and the optimal solution is at the corner, $h_1^* = 0$. (Optimal values are denoted by superscript (*) throughout.) The current health contribution rate, however, still appears to be close to optimal and life expectancy increases by 0.3 years compared to the status quo.

Given the higher importance of old age, individuals prefer to raise pension contributions as a fraction of labor income to 19.1 percent. Case 4 considers $\xi = 4$, which means that individuals are willing to work four years longer for a reduction of one health deficit. In this case it is optimal to further increase the health contribution rate by 4.8 percentage points from the status quo level, shift the health spending structure to the working aged and reduce the pension contribution rate from 18.7 to 16.6 percent. As a result both the optimal retirement age and life expectancy increases by almost a year. Thus, a healthy life is behind the veil of ignorance preferable against high consumption in retirement.

5.3 Labor Supply Elasticities

According to our calibration strategy based on (24), the labor supply elasticities and the elasticity of intertemporal substitution cannot be modified independently. Case 5 in Table 1 shows results for $\eta = 0.3$ (instead of 0.58) and keeping ε at benchmark value. This implies $\sigma = 0.7$, a value close to or below the lower end of empirical estimates. The dominating effect here is the reduced curvature of the utility function, implying that it is now optimal behind the veil of ignorance to spend less on health and consume more during retirement by raising the pension savings rate to about 20 percent. In particular, it is optimal to spend nothing at working age and consequently die somewhat earlier than in the status quo scenario.

By contrast, in Case 6, a value of $\eta = 0.9$ implies $\sigma = 1.1$, i.e. a relatively minor increase in curvature of the utility function. There is a pronounced impact on preferred health expenditure, in particular in old age. The optimal health contribution rate, τ_h^*, rises to 18.8 percent along with a reduction of the optimal pension savings rate, τ_s^*, to 17.8 percent. The optimal retirement age basically remains at 65 years.

In Case 7 we keep $\eta = 0.58$ from the baseline calibration and set $\varepsilon = 0.05$, a value closer to the estimates of the labor supply elasticity of single men (Bargain et al., 2014). The implied value of σ is 1.3, which causes a significant increase in the curvature of the utility function. As a result it is now optimal to drastically increase health spending such that individuals live for 2.3 years longer than in the status quo case and 1.8 years longer than in the benchmark scenario. Again, the optimal retirement age responds only mildly, increasing to 65.3 years. The optimal savings rate, τ_s^*, on the other hand, declines more pronouncedly from the status quo compared to the benchmark case, as a response to the greatly increased health contribution rate and the associated tax distortions of labor supply.

Finally, we investigate with Case 8 the role of pure leisure preference for retirement by increasing γ from 0.25 to 0.5. Consequently, the optimal age of retirement interacts more strongly with health spending, which both rise substantially. The optimal health contribution, τ_h^*, rises to 21.7 percent, along with a fall in τ_s^* to 15 percent. The optimal retirement age increases by 2.4 years, about one year more than life expectancy. The reduction in the expected number of health deficits is associated with an increase in health inequality.

Table 1: Optimal Health and Pension Policy

Case		h_1/h_2	τ_h	τ_s	$\bar{R}$	LE	$E(n_1)$	$E(n_2)$	$Gini_1$	$Gini_2$
1)	status quo	0.29	15.5	18.7	65.0	78.5	1.41	5.77	0.45	0.36
2)	benchmark	0.26	17.4	18.5	65.0	79.0	1.41	5.61	0.45	0.36
3)	$\xi = 0$	0	15.4	19.1	65.0	78.8	1.50	5.69	0.44	0.37
4)	$\xi = 4$	0.71	20.3	16.8	65.8	79.4	1.29	5.50	0.47	0.36
5)	$\eta = 0.3$	0	6.2	20.1	64.8	76.8	1.50	6.36	0.44	0.34
6)	$\eta = 0.9$	0.1	18.8	17.8	64.9	79.0	1.46	5.62	0.45	0.37
7)	$\epsilon = 0.05$	0.42	32.1	16.1	65.3	80.8	1.30	5.04	0.47	0.39
8)	$\gamma = 0.5$	0.91	21.7	15.0	67.4	79.8	1.24	5.42	0.48	0.36
9)	$\tau_w = 0.3$	0.12	14.6	17.8	64.9	78.4	1.46	5.82	0.45	0.36
10)	high tech	2	29.3	12.4	68.9	82.3	1.05	4.64	0.51	0.39
12)	$\delta = 0$	0.21	18.2	18.5	65.3	79.6	1.41	5.42	0.45	0.38

Policy parameters are jointly set to optimal values. $\bar{R}$ is the retirement age converted to years, LE is life expectancy at birth, $E(n_j)$ is expected health deficits in period $j \in \{1, 2\}$, $Gini_j$ is the Gini coefficient for health deficits in period j, τ_h and τ_s are expressed in percent; "high tech" corresponds to the case where all improvement of health for the working-aged from the year 1900 to 2000 can be attributed to advancement in medical technology.

5.4 Other Parameters

Our next numerical experiment considers a higher labor tax rate, $\tau_w = 0.3$ (Case 9). As a consequence, to cope with the high tax distortions of labor supply, τ_h^* and τ_s^* are now both lower than in the benchmark (Case 2). Per capita health spending is relatively more concentrated on the elderly and the retirement age is left unchanged.

Case 10 gives us first insights about the role of medical technology. For that purpose we now assume that, albeit unrealistically, all improvement in health during the 20th century can be attributed to medical technology ("high tech" scenario), i.e. we keep α_1 at its level from the year 1900. Fitting the survival curves of Figure 1 requires a re-calibration to $\beta_1 = 1.4$ and $\beta_2 = 1.0$. Not surprisingly it is now optimal to further increase health expenditure, in particular during working age. More health spending implies that the distribution of health deficits shifts to the left. The Markov-feature of health transitions causes the better health in working age to be transmitted to better health in old age and a longer life. Optimal policy interventions increase both retirement age and life expectancy by 3.9 years and substantially reduces the expected number of health deficits for both groups, $E(n_1)$, $E(n_2)$, compared to the status quo. Like in Case 8, this goes along with a significant increase in health inequality among both the working aged and the elderly, as measured by the Gini coefficient of health deficits. $Gini_1$ and $Gini_2$ increase by five and three percentage points, respectively.

Finally, in Case 11 we make the illustrative but empirically refuted assumption that health deficits are irrelevant for labor supply at the intensive margin (by setting $\delta = 0$). Naturally, it is now optimal to shift health expenditure from the young to the elderly. Moreover, as total labor supply and thus pension income is higher than in the benchmark scenario, all other things being equal, the distortionary effect of raising the health contribution rate, τ_h, is lower (see the proof of Proposition 2). It is thus optimal to increase τ_h (and leave τ_s basically unchanged), leading to a higher life expectancy than in the benchmark case.

6 Long-Run Perspectives on Social Insurance, Life Expectancy, and Health Inequality

The analysis in the previous section suggests for realistic parameter values that the current social insurance system in Germany is close to optimal. Deviations occur in the cases where the curvature in the consumption utility function departs significantly from log-utility or previous advancements in the health technology were very effective in boosting 20th century survival rates. In this section we use the model for out of sample predictions. In particular we are interested in the impact of future advances in medical technology on the optimal social insurance system and on health, life expectancy, and health inequality.

6.1 Optimal Response to Medical Improvements Compared to the Benchmark Run

In Case 1 of Table 2, we consider the model as parameterized for the benchmark run except that we increase both technology parameters β_1 and β_2 by factor 1.5. Under the status quo policy mix, this would correspond to an increase in life expectancy from 78.5 to 80.2 years (not shown). Under the optimal adjustment of the social insurance system, life expectancy increases to 82.5 years, another 2.3 years compared to no policy response. Technological progress makes further health expenditure desirable (τ_h^* increases by 7.3 percentage points compared to the benchmark run, Case 2 in Table 1), in particular for individuals at working age whose per capita health spending shall become as high as those of the elderly. Similar to the "high tech" scenario 10 in Table 1, a social planner would raise the retirement age but not to the extent than life expectancy increases. The policy shall be accompanied with a lower savings rate in order to finance increased health spending without increasing the total burden on labor income too much ($\tau_w + \tau_s^* + \tau_h^*$ increases by 4.7 percentage points compared to benchmark). Our findings thus suggest that, behind the veil of ignorance, individuals prefer a healthy life against high consumption in retirement. The result reflects the fact, emphasized by Hall and Jones (2007), that welfare is linear in the length of life but strictly concave in consumption per period. The last column of Table 2 shows the implied increase in the value of life. The value of life is predicted to increase by $\Delta W/W = 3.3$ percent, a huge amount, recalling that the move from status quo to optimal policy in the benchmark run (Case 1 to Case 2 in Table 1) improved the value of life by very little.

Table 2: Prediction of Future Trends under Optimal Policy Adjustment

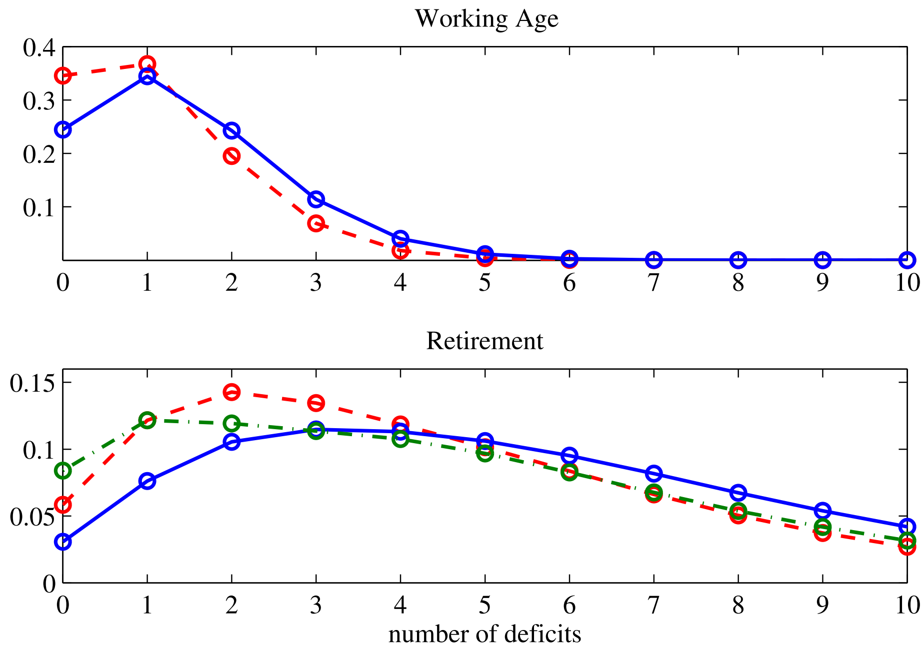
Case		tech.	h_1/h_2	τ_h	τ_s	$\bar{R}$	LE	$E(n_1)$	$E(n_2)$	$Gini_1$	$Gini_2$	$\frac{\Delta W}{W}$
1)	$\xi = 1$	equal	1.11	24.7	15.9	67.0	82.5	1.06	4.51	0.51	0.40	3.30
2)	$\xi = 1$	biased	0.15	17.3	20.7	64.9	81.9	1.44	4.73	0.45	0.42	3.51
3)	$\xi = 0$	equal	0.4	19.9	19.0	65.1	81.4	1.29	4.83	0.47	0.40	3.35
4)	$\xi = 0$	biased	0	15.8	21.2	65.0	81.7	1.50	4.81	0.44	0.42	3.66
5)	$\xi = 4$	equal	1.7	28.0	12.9	69.6	83.2	0.93	4.35	0.54	0.39	4.25
6)	$\xi = 4$	biased	0.38	19.7	19.4	65.4	82.3	1.36	4.62	0.46	0.42	3.65

Other parameters as for benchmark case. tech. equal: β_1 and β_2 increase by 50%. tech. biased: no change of β_1, β_2 increases by 100%. The last column indicates the welfare gain in percent.

The most interesting result is perhaps that health inequality is predicted to increase further through medical technological progress accompanied by optimal policy adjustment. $Gini_1$ and $Gini_2$ are given by 0.51 and 0.4, respectively (without policy adjustment, they become 0.46 and 0.38 respectively). Figure 4 illustrates why. Solid lines show the deficit distribution for the benchmark case and dashed (red) lines show the future prediction. Medical technology improves largely the health of those individuals in anyway good health at the left-hand side of the distribution but it has little impact on the right tail. The share of individuals in full health during working age and those with one or less health deficits in retirement increase substantially.

Case 2 in Table 2 assumes that medical technological progress is age-biased in the sense that all future advancement concern health in old age only (i.e. better treatment of old age diseases). We hold β_1 constant and assume that β_2 doubles. This corresponds to an increase in life expectancy to 81.2 years without policy adjustment and to 81.9 years with an optimal policy response. Compared to the benchmark, the optimal health contribution rate, τ_h^*, changes only marginally and health spending shall be shifted more to the elderly. The optimal retirement age approximately stays at 65 years and the optimal pension savings rate, τ_s^*, rises by 2.2 percentage points. Lacking technology advancements, health of the young changes only by little compared to the benchmark run. It deteriorates a bit through the

Figure 4: Deficit Distribution: Benchmark Case vs. Long-Run Prediction



Solid lines: optimal actual policy mix. Dashed lines: optimal future policy mix when β_1 and β_2 rise by factor 1.5. Dashed-dotted lines: optimal future policy when β_2 rises by factor 2 and β_1 stays constant.

shift toward old age expenditure. While expected health deficits $E(n_1)$ increase somewhat, $Gini_1$ stays constant. Visually the health distribution at working age cannot be distinguished from the benchmark case (it lies invisible behind the solid line in the upper panel of Figure 4). Health of the elderly improves significantly. Interestingly, however, $E(n_2)$ is reduced by less than for unbiased technological change, although the elderly experience more medical improvements than in Case 1 of Table 2. The reason is that retirees benefit only directly from technological change but not indirectly through transmission of better health from young age to old age. The impact of health transmission can also be seen by the health distribution in the bottom panel of Figure 4. Dashed-dotted (green) lines visualize the implications of doubling β_2 (and leaving the other parameters unchanged). Due to less transmission of good health there are actually less individuals in retirement with only a few health deficits than under unbiased technological change (dashed red lines).

6.2 Sensitivity Analysis

The remaining cases of Table 2 provide some sensitivity analysis with respect to the role of health deficits in disutility function V. For $\xi = 0$ both unbiased (Case 3) and age-biased (Case 4) medical progress induce a smaller optimal response of health spending than for $\xi = 1$ considered in Case 1 and Case 2, respectively, and consequently life expectancy improves by less. The pension savings rate shall be higher. With aged-biased progress, average health deficits of the young actually increases by even more compared to the benchmark case due to the shift of health expenditure to the elderly, and health inequality among the young is slightly lower than in Case 2. For $\xi = 4$ (Cases 5 and 6), on the other hand, optimal health spending induced by technological progress should increase more relative to the benchmark than for $\xi = 1$ and the pension savings rate shall be lower in order to limit tax distortions of labor supply. In case of unbiased technological change the desired retirement age also rises significantly, to almost 70 years, reflecting the substantially better health of workers that leads to an increase of life expectancy to 83.2 years. This is also the case that leads to the greatest improvement of the expected value of life and the greatest increase in health inequality among the working-aged.

6.3 Summary of Results

Summarizing, our analysis suggests that substantially increasing the health expenditure share can be regarded as optimal when medical technology improves. There are important implications on the distribution of health and the jointly optimal responses of the social security system that have yet not been worked out in the literature. While individuals want to exploit the possibility to prolong life by increasing the health contribution rate, they prefer to lower the pensions savings rate at the same time, accompanied by a higher retirement age. Also interestingly, more health spending, as a rule, leads to more health inequality. The reason is that thanks to the powerful health technology there are large gains in life expectancy for those who developed only a small number of health deficits. For the unlucky individuals at the right end of the health deficit distribution, however, health technology is still too weak in order to improve their health substantially. Stated differently, medical technological progress – with or without an optimal response from a social welfare point of view – is predicted to increase health inequality. Our analysis also shows that, in most cases, individuals prefer to increase the retirement age by a smaller factor than life expectancy, thus re-scaling the life-cycle towards relatively more leisure.

7 Conclusion

We integrated into public economics a biologically founded, stochastic process of individual ageing. We derived the optimal design of the social insurance system behind the veil of ignorance for the current health technology and in response to future medical progress, and investigated the implications for life expectancy and health inequality.

Our results from the calibrated model for Germany suggest that, currently, the PAYG health and pension system are jointly approximately optimal. The result is most sensitive to the coefficient of relative risk aversion, a parameter that fortunately has been pinned down well in the literature. Further improvements in the medical technology that raise life expectancy would call for potentially drastic increases in the health contribution rate. In case of medical progress that affects working-aged individuals and retirees equally, increased health spending shall be accompanied with potentially pronounced decreases in the pension savings rate. Thus, behind the veil of ignorance, individuals prefer a healthy and longer life against high consumption in retirement. The result reflects that life-time utility is linear in the length of life but concave in consumption per period. Typically, the retirement age should increase proportionally less than life expectancy.

Another important insight is that, as a rule, increasing health spending in response to life-prolonging medical innovations raises health inequality. The result is driven by the fact that higher health spending helps those who are relatively healthy more than those who have accumulated a rather high number of health deficits already. It is interesting in view of the debate on the distribution of health status in the population. For instance, the WHO explicitly aims at reducing "avoidable" health inequity that it is "attributable to the external environment and conditions mainly outside the control of the individuals concerned". Abstracting from behavioral decisions that may affect individual health, our analysis suggests that this goal may be in conflict with welfare maximization of *ex ante* identical individuals behind the veil of ignorance.

In future research we plan to endogenize the health technology, again in a model of health deficit accumulation that captures the basic stylized facts from gerontology research.[21] For instance, it is interesting to investigate how the incentive to innovate in the pharmaceutical sector interacts with the social insurance system. A framework with biologically founded human ageing would also allow us to examine to which degree health innovations should be promoted vis-à-vis non-health innovations.

Appendix

In this appendix, we derive and discuss the social welfare optimization problem behind the veil of ignorance. Using (3), (7), (8), (22) and $\mathcal{T} \equiv \tilde{\mathcal{T}}(h_1, \tau, \bar{R})$ as given by (23) in (4), utility of individual i can be written as

$$U(i) = \begin{cases} \hat{U}(n_1(i), h_1, \tau, \bar{R}) \text{ if } n_1(i) \in \bar{S} \\ \check{U}(n_1(i), h_1, \tau, \bar{R}) \text{ if } n_1(i) \in \underline{S} \text{ and } n_2(i) \in \bar{S} \\ \tilde{U}(n_1(i), n_2(i), h_1, h_2, \tau, \bar{R}) \text{ otherwise,} \end{cases} \tag{28}$$

where

$$\hat{U}(n_1, h_1, \tau, \bar{R}) \equiv -V(\tilde{T}(n_1), n_1) + \frac{1 - e^{-\rho \tilde{T}(n_1)}}{\rho} \times \\ \left(\frac{\tilde{C}_1(n_1, \tilde{w}(\tau), \tilde{\mathcal{T}}(h_1, \tau, \bar{R}))^{1-\sigma} - 1}{1 - \sigma} - \kappa(n_1) \frac{\tilde{l}(n_1, \tilde{w}(\tau), \tilde{y}(\tilde{\mathcal{T}}(h_1, \tau, \bar{R})))^{1+1/\eta}}{1 + 1/\eta} \right), \tag{29}$$

[21] In a recent paper, Grossmann (2013) studies the role of institutional regulations in the pharmaceutical sector and co-insurance schemes in the health system on pharmaceutical innovations. However, he does not capture the interactions with the social security system and does not endogenize life expectancy.

$$\check{U}(n_1,h_1,\tau,\bar{R}) \equiv -V(\bar{R},n_1) + \frac{1-e^{-\rho\bar{R}}}{\rho}\times \left(\frac{\tilde{C}_1(n_1,\tilde{w}(\tau),\tilde{\mathcal{T}}(h_1,\tau,\bar{R}))^{1-\sigma}-1}{1-\sigma} - \kappa(n_1)\frac{\tilde{l}(n_1,\tilde{w}(\tau),\tilde{y}(\tilde{\mathcal{T}}(h_1,\tau,\bar{R})))^{1+1/\eta}}{1+1/\eta}\right), \tag{30}$$

$$\tilde{U}(n_1,n_2,h_1,h_2,\tau,\bar{R}) \equiv -V(\bar{R},n_1) + \frac{1-e^{-\rho\bar{R}}}{\rho}\times \left(\frac{\tilde{C}_1(n_1,\tilde{w}(\tau),\tilde{\mathcal{T}}(h_1,\tau,\bar{R}))^{1-\sigma}-1}{1-\sigma} - \kappa(n_1)\frac{\tilde{l}(n_1,\tilde{w}(\tau),\tilde{y}(\tilde{\mathcal{T}}(h_1,\tau,\bar{R})))^{1+1/\eta}}{1+1/\eta}\right) + \frac{e^{-\rho\bar{R}}-e^{-\rho\tilde{T}(n_2)}}{\rho}\left(\frac{\tilde{C}_2(n_1,h_1,h_2,\tau,\bar{R},\tilde{\mathcal{T}}(h_1,\tau,\bar{R}))^{1-\sigma}-1}{1-\sigma}\right). \tag{31}$$

Expected welfare then reads as

$$W(h_1,h_2,\tau,\bar{R}) \equiv \sum_{n_1\in\bar{S}} g(n_1,\tilde{a}_1(h_1))\hat{U}(n_1,h_1,\tau,\bar{R}) + \sum_{n_1\in\underline{S}}\sum_{n_2\in\bar{S}} G(n_1,n_2,h_1,h_2)\check{U}(n_1,h_1,\tau,\bar{R}) + \sum_{n_1\in\underline{S}}\sum_{n_2\in\underline{S}} G(n_1,n_2,h_1,h_2)\tilde{U}(n_1,n_2,h_1,h_2,\tau,\bar{R}). \tag{32}$$

Thus, the optimal policy mix solves

$$\max_{h_1,h_2,\tau_h,\tau_s,\bar{R}} W(h_1,h_2,\tau,\bar{R}) \text{ s.t. } (17), \tag{33}$$

where labor supply functions $\tilde{l}(n_1,\cdot)$, $n_1 \in S$, are implicitly defined by (6).

Because of the various interactions between the health and pension system, (33) is a very complex optimization problem. For instance, consider the welfare interaction of the pension contribution rate, τ_s, with the health contribution rate, τ_h. On the one hand, raising τ_h may make an increase in τ_s less worthwhile and vice versa because contributions to the health system and the pension system come from the same source (labor earnings) and the marginal utility of consumption is declining. On the other hand, an increase in τ_h implies that individuals live longer, all other things equal, thus prolonging the retirement period. This raises the benefit to contribute more to the pension system, i.e. to increase τ_s

together with τ_h. If τ_h is increased such that life-time expands, it may seem a good idea to raise retirement age, $\bar{R}$, as well. This is often suggested in debates on demographic change. However, if $\bar{R}$ increases, the number of contributors to both tiers of the social insurance system, N_1, rises. It is thus not clear if contribution rates to either form of social insurance should be positively or negatively associated with the retirement age.

The analysis of the numerically calibrated version of the model disambiguates these analytical considerations to derive the socially optimal insurance system and assesses its implications on health inequality and welfare. It is instructive to look first at the simpler, deterministic case, where all individuals are identical also *ex post* and reach the retirement age. Since all individuals are identical, it is meaningless to assume redistribution among workers. Thus, $\tau_w = \mathcal{T} = 0$ and non-labor income y of workers is exogenous.

Define the net wage function for $\tau_w = 0$ as $\hat{w}(\tau_h, \tau_s) \equiv \tilde{w}(\tau_h, \tau_s, 0)$. As $R(i) = \bar{R}$ for all i and cohort size is normalized to unity, the mass of working-aged individuals and retirees is

$$N_1 = \bar{R},\ N_2 = \tilde{T}(n_2) - \bar{R}, \tag{34}$$

respectively. In view of (10) and (11), with a degenerated density function g, the number of health deficits of each individual in period 1 and 2 of life equals

$$n_1 = a_1 = \tilde{a}_1(h_1), \tag{35}$$

$$n_2 = a_2 + bn_1 = \tilde{a}_2(h_2) + b\tilde{a}_1(h_1). \tag{36}$$

The relationship between health spending for the working-aged and for retirees reads as $N_1 h_1 + N_2 h_2 = \tau_h \bar{R} \omega \tilde{l}(n_1, \cdot)$. Using (34), (35) and (36), we have

$$h_1 + \left(\frac{\tilde{T}(\tilde{a}_2(h_2) + b\tilde{a}_1(h_1))}{\bar{R}} - 1 \right) h_2 = \tau_h \omega \tilde{l}(\tilde{a}_1(h_1), \hat{w}(\tau_h, \tau_s), y), \tag{37}$$

implicitly defining $h_2 \equiv \tilde{h}_2(h_1, \tau_h, \tau_s, \bar{R})$ as a function of the other policy instruments. Using this in (36) leads to

$$n_2 = \tilde{a}_2(\tilde{h}_2(h_1, \tau_h, \tau_s, \bar{R})) + b\tilde{a}_1(h_1) \equiv \tilde{n}_2(h_1, \tau_h, \tau_s, \bar{R}). \tag{38}$$

According to (8) and (35), at each instant, consumption of working-aged individuals is given by

$$C_1 = \hat{w}(\tau_h, \tau_s)\tilde{l}(\tilde{a}_1(h_1), \hat{w}(\tau_h, \tau_s), y) + y. \tag{39}$$

Equating aggregate expenses to aggregate contributions in the pension system, $N_2 C_2 = N_1 \tau_s w \tilde{l}(n_1, \hat{w}(\tau_h, \tau_s), y)$, and using (34), (35) and (38), we find that the pension benefit per retiree at each instant reads as

$$C_2 = \frac{\bar{R}\tau_s w \tilde{l}(\tilde{a}_1(h_1), \hat{w}(\tau_h, \tau_s), y)}{\tilde{T}(\tilde{n}_2(h_1, \tau_h, \tau_s, \bar{R})) - \bar{R}}. \tag{40}$$

Using (35), (39), (40) and $T = \tilde{T}(n_2)$ in (4), individual welfare reads as

$$\begin{aligned} U = &-V(\bar{R}, \tilde{a}_1(h_1)) + \frac{1 - e^{-\rho\bar{R}}}{\rho} \times \\ &\left(\frac{\left[\hat{w}(\tau_h, \tau_s)\tilde{l}(\tilde{a}_1(h_1), \hat{w}(\tau_h, \tau_s), y) + y\right]^{1-\sigma} - 1}{1-\sigma} - \kappa(\tilde{a}_1(h_1)) \frac{\tilde{l}(\tilde{a}_1(h_1), \hat{w}(\tau), y)^{1+1/\eta}}{1 + 1/\eta} \right) + \\ &\frac{e^{-\rho\bar{R}} - e^{-\rho\tilde{T}(n_2)}}{\rho} \left(\frac{\left[\frac{\bar{R}\tau_s w \tilde{l}(\tilde{a}_1(h_1), \hat{w}(\tau_h, \tau_s), y)}{\tilde{T}(n_2) - \bar{R}}\right]^{1-\sigma} - 1}{1-\sigma} \right) \equiv u(h_1, \tau_h, \tau_s, \bar{R}, n_2). \end{aligned} \tag{41}$$

A social planer sets policy parameters to solve

$$\max_{h_1 \geq 0, \tau_h \in [0,1], \tau_s \in [0,1], \bar{R} \in [0, T_{\max}], n_2 \in S} u(h_1, \tau_h, \tau_s, \bar{R}, n_2) \text{ s.t. } n_2 = \tilde{n}_2(h_1, \tau_h, \tau_s, \bar{R}). \tag{42}$$

Denote by $(h_1^*, \tau_h^*, \tau_s^*, \bar{R}^*)$ the solution to (42) with respect to the policy variables. The optimal health spending targeted to the retirees is inferred as $h_2^* \equiv \tilde{h}_2(h_1^*, \tau_h^*, \tau_s^*, \bar{R}^*)$. As claimed in the main text, we now show that the optimal allocation of health spending towards working-aged and retired individuals, (h_1^*, h_2^*), maximizes life-time.[22] To avoid only mildly interesting discussions about potential corner solutions, we focus our analysis on interior solutions of (42).

Proposition A.1. *Suppose that $(h_1^*, \tau_h^*, \tau_s^*, \bar{R}^*)$ is an interior maximizer of (42). Then the optimal allocation of health spending across periods of life maximizes life expectancy if and only if $\kappa' = 0$ and V does not depend on n_1.*

Proof. Define $\mathbf{z} \equiv (h_1, \tau_h, \tau_s, \bar{R})$. We need to establish that at an interior solution to (42), $\mathbf{z}^* \equiv (h_1^*, \tau_h^*, \tau_s^*, \bar{R}^*)$, the following holds: (i) If $\kappa' = 0$ and V does not depend on n_1, then $\partial \tilde{n}_2(\mathbf{z}^*)/\partial h_1 = 0$; (ii) if $\kappa' > 0$ or $\partial V/\partial n_1 > 0$, then $\partial \tilde{n}_2(\mathbf{z}^*)/\partial h_1 > 0$. To see this, let us define $\hat{u}(\mathbf{z}) \equiv u(\mathbf{z}, \tilde{n}_2(\mathbf{z}))$, $\Phi(\mathbf{z}, n_2) \equiv \partial u(\mathbf{z}, n_2)/\partial n_2$ and $\hat{\Phi}(\mathbf{z}) \equiv \Phi(\mathbf{z}, \tilde{n}_2(\mathbf{z}))$. Using (41), we obtain the following partial derivatives of $\hat{u}(\mathbf{z})$ with respect to h_1 and τ_h:

$$\frac{\partial \hat{u}}{\partial h_1} = \hat{\Phi}\frac{\partial \tilde{n}_2}{\partial h_1} + \frac{1-e^{-\rho\bar{R}}}{\rho}\left(\frac{\partial \tilde{l}}{\partial n_1}\underbrace{[(C_1)^{-\sigma}\hat{w} - \kappa \tilde{l}^{1/\eta}]}_{=0, \text{ acc. to (6)}} - \kappa' \frac{\tilde{l}^{1+1/\eta}}{1+1/\eta}\right)\tilde{a}_1' + \frac{e^{-\rho\bar{R}} - e^{-\rho\tilde{T}(n_2)}}{\rho}(C_2)^{-\sigma}\frac{\bar{R}w\tau_s}{\tilde{T}(n_2)-\bar{R}}\frac{\partial \tilde{l}}{\partial n_1}\tilde{a}_1' - \frac{\partial V}{\partial n_1}\tilde{a}_1', \tag{43}$$

$$\frac{\partial \hat{u}}{\partial \tau_h} = \hat{\Phi}\frac{\partial \tilde{n}_2}{\partial \tau_h} - \frac{1-e^{-\rho\bar{R}}}{\rho}\frac{\partial \tilde{l}}{\partial \hat{w}}w\underbrace{[(C_1)^{-\sigma}\hat{w} - \kappa \tilde{l}^{1/\eta}]}_{=0, \text{ acc. to (6)}} - \frac{e^{-\rho\bar{R}} - e^{-\rho\tilde{T}(n_2)}}{\rho}(C_2)^{-\sigma}\frac{\bar{R}\tau_s w}{\tilde{T}(n_2)-\bar{R}}\frac{\partial \tilde{l}}{\partial \hat{w}}w, \tag{44}$$

where we used the fact $\partial \hat{w}/\partial \tau_h = -w$ in (44). Also note that $(C_1)^{-\sigma}\hat{w} = \kappa \tilde{l}^{1/\eta}$, according to (6). According to (38), we have

$$\frac{\partial \tilde{n}_2}{\partial h_1} = \tilde{a}_2' \frac{\partial \tilde{h}_2}{\partial h_1} + b\tilde{a}_1', \tag{45}$$

$$\frac{\partial \tilde{n}_2}{\partial \tau_h} = \frac{\partial \tilde{h}_2}{\partial \tau_h}\tilde{a}_2', \tag{46}$$

[22] For analytical simplicity, we treat health deficits n_1 and n_2 as (non-negative) real numbers rather than as integers.

At the optimum, there cannot be Laffer effects, i.e. $\partial\tilde{h}_2/\partial\tau_h \geq 0$. Thus, (46) and $\tilde{a}_2' < 0$ imply that

$$\frac{\partial\tilde{n}_2(\mathbf{z}^*)}{\partial\tau_h} \leq 0. \tag{47}$$

Hence, at an interior solution $\mathbf{z}^*$ to (42), where $\partial\hat{u}(\mathbf{z}^*)/\partial\tau_h = 0$, we have

$$\hat{\Phi}(\mathbf{z}^*) < 0, \tag{48}$$

according to (43). Recall that $\partial\tilde{l}/\partial n_1 < (=)0$ if and only if $\kappa' > (=)0$. By definition of $\mathbf{z}^*$, $\partial\hat{u}(\mathbf{z}^*)/\partial h_1 = 0$. The properties thus follow from (43), (48) and $\tilde{a}_1' < 0$. This concludes the proof. ■

If an increase in health spending targeted to the working-aged has no effect on labor supply ($\kappa' = 0$) and individuals do not care about health status per se (i.e. V does not depend on n_1), then the social planer wants to maximize the span of life in which individuals earn retirement income. This is achieved by minimizing health deficits of the elderly, $n_2 = \tilde{n}_2(h_1, \tau_h, \tau_s, \bar{R})$. If $\kappa' > 0$, however, an increase in labor supply that results from an increase in health expenditure, h_1, raises contributions to the pension system. Hence, it is optimal to sacrifice life-time to improve consumption in each point of time for both working-aged individuals and retirees. Also if workers have direct disutility from illness (V is increasing in n_1), the social planer biases the health spending structure towards workers. Proposition A.1 would also hold under a "constrained optimal policy mix" where pension policy $(\tau_s, \bar{R})$ is treated as given.

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