TU WIEN SWM ECON Economics

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March 2018

Health insurance, endogenous medical progress, and health expenditure growth

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Working Paper 01/2018

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March 27, 2018

Abstract

We study the impact of health insurance expansion in the US on health expenditure, longevity growth and welfare in an overlapping generations economy in which individuals purchase health care to lower mortality. We consider three sectors: final goods production; a health care sector, selling medical services to individuals; and an R&D sector, selling increasingly effective medical technology to the health care sector. We calibrate the model to match the development of the US economy/health care system from 1965 to 2005 and study numerically the impact of the insurance expansion on health expenditures, medical progress and longevity. We find that more extensive health insurance accounts for a large share of the rise in US health spending but also boosts the rate of medical progress. A welfare analysis shows that while the moral hazard associated with subsidized health care creates excessive health care expenditure, the gains in life expectancy brought about by induced medical progress more than compensate for this. By mitigating an intergenerational externality associated with the longevity benefits from current medical innovation the expansion of health insurance constitutes a Pareto improvement.

Keywords: life-cycle model, health care spending, health insurance, medical progress, moral hazard, overlapping generations.

JEL-Classification: D15, I11, I12, I18, J11, J17, O31, O41.

[*]We are grateful to Hans Fehr, Volker Grossmann, Franz Hof, Mathias Kifmann, Norman Lorenz, Michael Pflüger, Jon Skinner, Pete Smith, Holger Strulik, Timo Trimborn, Joachim Winter and Peter Zweifel for helpful comments and discussions. Financial support for this research by the Austrian Science Fund under grant P 26184-G11 is gratefully acknowledged. The responsibility for any errors lies entirely with us.

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1 Introduction

In the United States, the share of the GDP spent on health care grew from 5 percent in 1960 to 17.5 percent in 2014 (see Figure 1). A steady stream of research has emerged that enquires into the causes of this dramatic development. Since the seminal work by Newhouse (1992), medical progress has been recognized as a main driver of medical spending growth, with income growth (Hall and Jones 2007) and the expansion of social security (Zhao 2014) playing an additional role.[1] According to recent analysis by Fonseca et al. (2013) about 30 percent of health care spending growth in the US over the period 1965-2005 can be explained by medical progress.

Interestingly, health insurance continues to be assigned only a minor role in most of the research on the theme. In light of the rapid expansion of health insurance in the US (see Figure 1), where out-of-pocket spending fell from around 55 percent in 1960 to around 15 percent in 2005 (Baicker and Goldman 2011), this is somewhat surprising, especially when considering the prominence that is assigned to moral hazard incentives in health insurance (e.g. Zweifel and Manning 2000). While early research by Feldstein (1971, 1977) identified the expansion of health insurance as a major driver of the increase in health care spending, the seminal research building on the RAND health insurance experiment pointed the opposite direction: in light of a rather modest price elasticity of health care spending, insurance could not really explain the spending boom (Manning et al. 1987, Newhouse 1992).

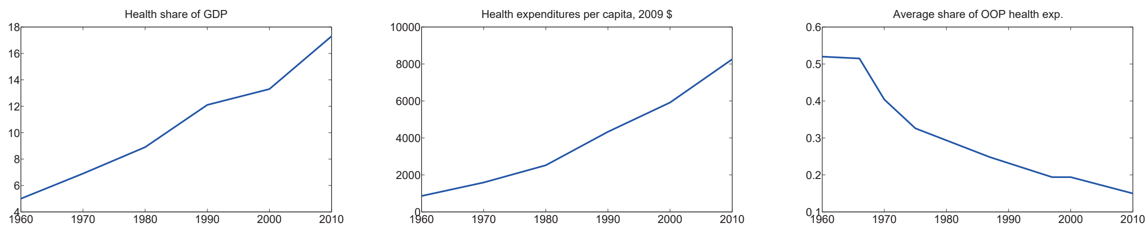

Figure 1: Health share of GDP, health expenditures per capita in 2009 $ and average share of out-of-pocket expenditures (OOP) in the US from 1960 to 2010. Data sources are discussed in section 3.1.

A conjecture by Weisbrod (1991) suggests a more indirect pathway through which health insurance may bear on the development of health expenditure: He hypothesizes that the expansion of

[1] See Chernew and Newhouse (2011) and Chandra and Skinner (2012) for two recent surveys on medical spending growth in general and its relation to medical progress in particular.

health insurance coverage created incentives to develop new medical technology. Clemens (2013) finds empirical support for this hypothesis: about 25 percent of recent medical-equipment innovation is explained by the expansion of US health insurance over the second half of the 20th century.[2] In a related analysis, Finkelstein (2007) shows that health insurance, does, indeed, explain a spending increase that is more than six times larger than the one suggested by the RAND health insurance experiment once macro-economic responses, such as induced entry into the hospital market, are accounted for. She also provides evidence that is suggestive of the adoption of new (cardiac) technologies following the introduction of Medicare.

This paper develops and analyses a macro-economic model of the insurance-spending-innovation nexus in order to provide a more complete understanding of the mechanisms underlying the empirical findings by Finkelstein (2007) and Clemens (2013). Specifically, we study an OLG economy with a realistic demographic structure, in which consumers demand health care for the purpose of lowering mortality. Health care is provided within a medical sector, and the demand for medical innovations, in turn, follows as a derived demand on the part of health care providers. Both the health care sector and the medical R&D sector employ capital and labour, competing for resources with a final goods production sector. We calibrate the model to reflect the development of the US economy over the time span 1965-2005 as it occurred in the presence of expanding health insurance. Against this benchmark, we then study a counterfactual scenario in which we freeze the coverage of health insurance at its 1965 level, i.e. the level before the introduction of Medicare. Our results show that the expansion of health insurance has, indeed, contributed strongly to the expansion of health care spending, and that induced medical progress plays a significant role in this.

Quantitatively, medical progress and insurance expansion can each explain about 14% of the 1965-2005 expenditure increase in isolation, whereas income growth explains about 16%. Similar to Fonseca et al. (2013), the remaining 56% of the expenditure increase are explained by complementarities between the three drivers. When comparing the development of health care expenditure per capita in the benchmark scenario against a counterfactual scenario in which insurance is frozen at its 1965 level, we find that the expansion of health insurance explains about 60% of the expen-

[2] Similarly, Baker (2001) and Baker and Phibbs (2002) find that increasing HMO market shares, implying less generous insurance coverage, were associated with slower diffusion and lower availability of the high-cost magnetic resonance imaging technology as well as the spread of neonatal intensive care units.

Acemoglu and Linn (2004) and Finkelstein (2004) find a large impact of potential market size on the development of new medical drugs and vaccines, respectively.

diture increase. This compares well with Finkelstein's (2007) finding, based on an extrapolation of her Medicare estimates, that the general expansion of health insurance explains about 50% of the spending increase from 1950 to 1990.

We also find that the expansion of health insurance has induced substantial medical R&D. Namely, it raises the rate of medical progress by about 41%, a figure that compares to an estimate of 33% by Clemens (2013) who is, however, only accounting for the impact of Medicare/Medicaid but not for the expansion of private health insurance. We then decompose the insurance induced increase in health care spending into a moral hazard effect associated with the subsidization of health care, and the spending increase associated with induced medical change. While moral hazard explains about 81% of the insurance-induced increase in health care spending, the opposite is true for the impact on life-expectancy: Overall, the expansion of health insurance has contributed 2.3 years to the increase in life expectancy between 1965 and 2000. Two of these years are attributable to insurance-induced medical innovations, whereas the "pure" insurance effect contributed only 0.3 years.

These findings suggest an ambivalent role of health insurance expansion. Abstracting in our model from shocks to health care spending, the insurance expansion is *wasteful for a given path of medical progress* by generating a substantial increase in health care spending without much gain in health outcomes, a typical moral hazard effect. The distortion from moral hazard is offset, however, by the *inducement of additional medical progress, which is generating substantial benefits*. A comparison of the lifetime utility of the birth cohorts 1900-1980 reveals that while the moral hazard effect per se is, indeed, generating (modest) welfare losses for most of the birth cohorts, these are overturned by a large margin when induced medical progress is taken into account. Indeed, we find that all cohorts have benefited from the expansion of health insurance, the gain being strongest for later-born cohorts. While in part this result is driven by an increasing willingness to pay for longevity-enhancing medical innovations within a growing economy and therefore a willingness to tolerate a growing drag on consumption growth (Hall and Jones 2007, Jones 2016, Kuhn and Prettner 2016), we show that the finding also holds in a counterfactual scenario in which GDP stagnates at its 1965 level.

This demonstrates the relevance of two intergenerational externalities: On the one hand, contemporary individuals spend insufficiently on health care, as they are not accounting for the benefits of demand-induced medical innovations for others individuals, both contemporary and yet unborn. Albeit inefficient from a static point of view, the expansion of health insurance then amounts to a subsidy prone to mitigate the externality. On the other hand, especially retired individuals spend excessively under Medicare insurance and, thereby, impose an externality on tax-paying working-aged individuals. Strikingly, it is this second externality which renders higher spending attractive to early born cohorts, who are close to retirement at the 1965 introduction of Medicare and who do not benefit much from future medical innovations. While later born, working-age cohorts are exposed to tax increases due to moral hazard, they are at the same time benefitting in their old age from the medical innovations, thus, induced. Altogether, the expansion of health insurance is leading to a Pareto improvement.

To our knowledge, the present study constitutes the first comprehensive macro-economic analysis of the role of health insurance as a stimulus of medical progress. Beyond replicating the empirical findings by Finkelstein (2007) and Clemens (2013) our model allows for a more detailed decomposition of the various channels through which income, health insurance, and medical progress bear on health expenditure and longevity; and for an analysis of the welfare consequences. Other papers dealing with endogenous medical progress are Jones (2016) who considers the optimal mix of medical R&D as opposed to conventional R&D from a social planner perspective, and Koijen et al. (2016) who study the impact of regulatory risks on medical innovation. Apart from the obvious difference in the policy focus, our key distinction from Jones (2016) is that he does not consider the evolution of medical progress in a decentralized economy, whereas our key distinction from Koijen et al. (2016) is the overlapping generations framework with endogenous mortality. Neither of the studies focuses on the impact of health insurance.[3] Closer in spirit, Böhm et al. (2017) consider the role of R&D-driven medical progress which improves health and longevity within an OLG economy through raising the effectiveness of publicly provided health care. Studying the trade-off between containing health care spending and granting access to medical progress, the authors also find that the gains from medical progress outweigh the savings on expenditure. Their work differs from ours in a number of dimensions. Most importantly, they do not consider the private demand for health

[3] Clemens (2013) motivates his empirical analysis of insurance-induced innovation by a partial equilibrium model of "innovation-by-doing" on the part of physicians. In contrast, our contribution amounts to a full general equilibrium account with a medical R&D sector that is distinct from the health care sector, and a set of overlapping generations of consumers with endogenous demand for health care.

care nor the role of health insurance in steering this demand. Their calibration being based on the UK NHS, they rather consider a public health care system with direct rationing. Furthermore, their numerical experiments are forward looking (up to the year 2050) rather than backward looking such as ours.[4]

The macro-economic impact of health insurance (reform) features in Jung and Tran (2016) and Conesa et al. (2017) who study the impact on economic performance and welfare of the introduction of the 2010 Affordable Care Act (Obama Care) and of a (hypothetical) removal of Medicare, respectively. Examining in a way the reverse scenario to ours, Conesa et al. (2017) find that while consumers would benefit in a new steady state without Medicare, even the cumulated welfare gains would be lower than the welfare loss along the transition path.[5] Neither of the two studies considers medical progress. Our paper is thus complementary to these works in as far as they study the trade-off between moral hazard and the direct gains from insurance, whereas we are considering the trade-off between moral hazard and the dynamic benefits generated from health insurance through the stimulation of medical progress.[6] In combination with Conesa et al. (2017) our results suggest a strong case for maintaining health insurance. While Conesa et al. (2017) find that health insurance should not be abolished owing to high short-term welfare losses, we find it should not be abolished owing to the inducement of medical progress with lasting long-term benefits.

The remainder of the paper is organized as follows. The following section introduces the model and characterizes the individual life-cycle optimum and general equilibrium. Section 3 introduces the numerical calibration and presents the findings for the benchmark. Section 4 explores by way of various counterfactual experiments the role of health insurance, income and social security as drivers of medical change, as well as the implications for the development of health expenditure. It also features a welfare analysis and a robustness exercise. Section 5 concludes. Some proofs and formal elements of the analysis have been relegated to an Appendix.

[4]Our work is also related to a literature examining the role of exogenous medical progress on health care expenditure and economic performance (Suen 2009, Fonseca et al. 2013, Schneider and Winkler 2016, Frankovic et al. 2017).

[5]One additional difference to Conesa et al. (2017) is that their model does not embrace a specific health care sector. As emerges from the analyses in Kuhn and Prettner (2016) and Frankovic et al. (2017), respectively, the reallocation of production factors across sectors plays a significant role, however, in channeling the economic impact of changes to the health care system.

[6]This is similar to what Bhattacharya and Packalen (2012) call ”the other ex-ante moral hazard”, which they consider, however, in a quasi-static partial equilibrium setting.

2 The Model

2.1 Individual problem

We consider an OLG model in which cohorts of representative individuals choose consumption and health care over their life-course. Individuals are indexed by their age a at time t, with $t_0 = t - a$ denoting the birth year of an individual aged a at time t. At each age, the cohort-representative individual is subject to a mortality risk, where $S(a,t) = \exp\left[-\int_0^a \mu(\hat{a}, h(\hat{a},\hat{t}), M(\hat{t}))d\hat{a}\right]$ is the survival function at (a,t), with $\mu(a, h(a,t), M(t))$ denoting the force of mortality. Following Frankovic et al. (2017) we assume that mortality can be lowered by the consumption of health care $h(a,t)$, the impact of which depends on the state of the medical technology $M(t)$ at time t. More specifically, we assume that the mortality rate $\mu(a, h(a,t), M(t))$ satisfies

$$
\begin{aligned}
\mu(a, h(a,t), M(t)) &\in (0, \tilde{\mu}(a,t)] \quad \forall\,(a,t)\,; \\
\mu_h(\cdot) &< 0,\ \mu_{hh}(\cdot) > 0; \\
\mu_h(a, 0, M(t)) &= -\infty,\ \mu_h(a, \infty, M(t)) = 0 \quad \forall\,(a,t)\,; \\
\mu_M(\cdot) &< 0,\ \mu_{MM}(\cdot) \geq 0,\ \mu_{hM}(\cdot) < 0 \quad \forall\,(a,t)\,.
\end{aligned}
$$

where $\tilde{\mu}(a,t) = \mu(a, 0, M(t))$ is the "natural "mortality rate for an individual aged a at time t when no health care is consumed. By purchasing health care, an individual can lower the instantaneous mortality rate, and can thereby improve survival prospects, but can only do so with diminishing returns.[7] Medical technology, in turn, enhances the returns to health care. While this assumption is not self-evident, it is consistent with empirical evidence that medical progress boosts the demand for medical care (see e.g. Baker et al. 2003, Cutler and Huckman 2003, Wong et al. 2012, and Roham et al. 2014).

Individuals enjoy period utility $u(c(a,t))$ from consumption $c(a,t)$. Period utility is increasing and concave: $u_c(\cdot) > 0$, $u_{cc}(\cdot) \leq 0$. Individuals maximize the present value of their expected life-cycle utility

$$\max_{c(a,t),h(a,t)} \int_0^{\omega} e^{-\rho a} u(c(a,t)) S(a,t) da \tag{1}$$

[7] Zweifel et al. (2005) provide empirical evidence of decreasing returns to health expenditure in the reduction of mortality. The decreasing returns assumption is also reflected in other empirical work on the relationship between health care and mortality (e.g., Hall and Jones 2007, Baltagi et al. 2012).

by choosing a stream of consumption and health care on the interval $[0, \omega]$, with ω denoting the maximal possible age, with $\rho \geq 0$ denoting the rate of time preference, and with $S(a,t)$ denoting the survival function.[8] While we will continue to read $S(a,t)$ as survival, the function may be interpreted as a more general measure of health that is subject to depreciation over the life-course (see e.g. Chandra and Skinner 2012 or Kuhn et al. 2015). For the representative individual the assumption that health care can slow down but not reverse the decline of health over the life course is plausible and well in line with evidence on the gradual accumulation of health deficits over the life course (Rockwood and Mitnitski, 2007; Dalgaard and Strulik 2014). Assuming that utility from consumption and utility from good health are multiplicatively separable, one could then generalize the interpretation of (1) to include not only health-dependent duration of life but also health-dependent quality of life.

The individual faces as constraints the dynamics of survival and the dynamics of individual assets $k(a,t)$, as described by[9]

$$\dot{S}(a,t) = -\mu(a, h(a,t), M(t))S(a,t), \tag{2}$$

$$\begin{aligned} \dot{k}(a,t) &= r(t)\,k(a,t) + l(a)w(t) - c(a,t) \\ &\quad -\phi(a,t)\,p_H(t)h(a,t) - \tau(a,t) + \pi(a,t) + s(t), \end{aligned} \tag{3}$$

with the boundary conditions

$$S(0,t_0) = 1, \quad S(\omega, t_0+\omega) = 0 \tag{4}$$

$$k(0,t_0) = k(\omega, t_0+\omega) = 0. \tag{5}$$

Here, (2) describes the reduction of survival under the force of mortality. According to (3) an individual's stock of assets $k(a,t)$ (i) increases with the return on the current stock, where $r(t)$ denotes the interest rate at time t; (ii) increases with earnings $l(a)w(t)$, where $w(t)$ denotes the

[8] Note that from the individual's perspective age and time progress simultaneously, following the identity $a \equiv t - t_0 \in [0,\omega]$ for $t \in [t_0, t_0+\omega]$. Thus, we have $\int_0^\omega e^{-\rho a} u(c(a,t))S(a,t)da = \int_0^\omega e^{-\rho a} u(c(a,t_0+a))S(a,t_0+a)da = \int_{t_0}^{t_0+\omega} e^{-\rho t} u(c(t-t_0,t))S(t-t_0,t)dt$.

[9] In the following, we will use the $\dot{()}$ notation to indicate both the derivative $\dot{x}(a,t) := x_a + x_t$ for life-cycle variables and the derivative $\dot{X}(t) := X_t$ for aggregate variables. Drawing again on the identity $t \equiv t_0 + a$ from the individual's perspective, it follows that $\dot{x}(a,t)$ collapses into a single dimension.

wage rate at time t, and where $l(a)$ denotes an individual's effective age-dependent labour supply; (iii) decreases with consumption, the price of consumption goods being normalized to one; (iv) decreases with private health expenditure, $\phi(a,t)\, p_H(t) h(a,t)$, where $p_H(t)$ denotes the price for health care, and where $\phi(a,t)$ denotes an (a,t)-specific rate of coinsurance; (v) decreases with an (a,t)-specific tax, $\tau(a,t)$; (vi) increases with (a,t)-specific benefits $\pi(a,t)$; and (vii) increases with a transfer $s(t)$ by which the government redistributes accidental bequests in a lump-sum fashion. We follow Suen (2009), Zhao (2014) and others by considering a setting without an annuity market. Finally, we assume that the survival function is bounded between 1 at birth and 0 at the maximum feasible age ω [see (4)], and that individuals enter and leave the life-cycle without assets [see (5)].

2.2 Aggregation

Denoting by $B(t-a)$ the size of the birth cohort at $t_0 = t-a$, the cohort aged a at time t has the size

$$N(a,t) = S(a,t)B(t-a).$$

By aggregating over the age-groups who are alive at time t we obtain the following expressions for the population size,[10] aggregate capital stock, aggregate effective labour supply, aggregate consumption, aggregate demand for health care, aggregate fiscal income from taxation, and aggregate social security payments, each at time t:

$$\begin{aligned}
N(t) &= \int_0^\omega S(a,t)B(t-a)da, & (6)\\
K(t) &= \int_0^\omega k(a,t)S(a,t)B(t-a)da, & (7)\\
L(t) &= \int_0^\omega l(a,t)S(a,t)B(t-a)da, & (8)\\
C(t) &= \int_0^\omega c(a,t)S(a,t)B(t-a)da, & (9)\\
H(t) &= \int_0^\omega h(a,t)S(a,t)B(t-a)da, & (10)\\
\Upsilon(t) &= \int_0^\omega \tau(a,t)\, S(a,t)B(t-a)da, &\\
\Pi(t) &= \int_0^\omega \pi(a,t)\, S(a,t)B(t-a)da. &
\end{aligned}$$

[10] In a slight abuse of notation, $N(t)$ denotes the population size at time t, whereas $N(a,t)$ represents the size of the cohort aged a at time t.

2.3 Production

The economy consists of a manufacturing sector, a health care sector and a medical R&D sector. In the manufacturing sector a final good is produced by employment of capital $K_Y(t)$ and labour $L_Y(t)$ according to a neoclassical production function

$$Y(A_Y(t), K_Y(t), L_Y(t)) = A_Y(t)K_Y(t)^{\alpha}L_Y(t)^{1-\alpha}, \tag{11}$$

with $A_Y(t)$ denoting total factor productivity in final goods production. A manufacturer's profit can then be written as

$$V_Y(t) = Y(A_Y(t), K_Y(t), L_Y) - w(t)L_Y(t) - [\delta + r(t)]\, K_Y(t) \tag{12}$$

with $\delta \geq 0$ denoting the rate of capital depreciation. Note that $V_Y(t) = 0$ in a competitive equilibrium.

Health care goods and services are produced by employment of labour $L_H(t)$, and capital $K_H(t)$ according to the production function

$$F(A_H(t), K_H(t), L_H(t)) = A_H(t)K_H(t)^{\beta_1}L_H(t)^{\beta_2}, \tag{13}$$

with $\beta_1 + \beta_2 < 1$, implying decreasing returns to scale, and with $A_H(t)$ denoting total factor productivity in the health care sector. In assuming decreasing returns to scale we follow Acemoglu and Finkelstein (2008) who study the impact of the introduction of prospective reimbursement on hospitals' input choices. They show that the increase in labour costs following the introduction of prospective reimbursement has led to a reduction of labour inputs but not of capital inputs. As they argue, this is consistent only with a decreasing returns to scale technology. Decreasing returns to scale imply the presence of quasi-fixed factors at the level of the individual provider and, more importantly in our case, at the sectoral level. Bilodeau et al. (2000), Bilodeau et al. (2004) and Ouellette and Vierstraete (2004) show that quasi-fix physician supply and capital in the hospital sector lead to a deviation from long-run cost minimization at the hospital level and to decreasing returns and a failure for productivity change to lead to cost savings at the sectoral level. In addition, Cremieux et al. (2005) show that lacking flexibility in the adjustment of certain bottleneck outcomes implies that increases in total demand come with cost increases both in private and public hospital markets. They also show that these rigidities are aggravated by technological progress. We thus believe our assumption of decreasing returns to be well founded.

Recalling the price for health care $p_H(t)$, the profit of a health care provider is then given by

$$V_H(t) = p_H(t)\, F(A_H(t), K_H(t), L_H(t)) - w(t)L_H(t) - [\delta + r(t)]\, K_H(t). \tag{14}$$

Note that decreasing returns to scale in the health care sector imply $V_H(t) > 0$, i.e. the existence of a producer rent, in a competitive equilibrium. Finally, we assume a medical R&D sector, the output of which is augmenting the state of medical technology $M(t)$ according to

$$\dot{M}(t) = G(A_M(t), K_M(t), L_M(t)) = A_M(t)K_M(t)^{\gamma}L_M(t)^{1-\gamma}, \tag{15}$$

with $K_M(t)$, $L_M(t)$ and $A_M(t)$, respectively, denoting capital and labour inputs as well as total factor productivity in the medical R&D sector. Profits in the medical R&D sector are then given by

$$V_M(t) = p_M(t)\, G(A_M(t), K_M(t), L_M(t)) - w(t)L_M(t) - [\delta + r(t)]\, K_M(t). \tag{16}$$

with $p_M(t)$ denoting the price for new medical technology. Again, we have $V_M(t) = 0$ in a competitive equilibrium. Note, that total factor productivity in the R&D sector is not $M(t)$, such that we do not model the standing on shoulder of giants effect. The productivity of health care in lowering mortality, $M(t)$, will grow endogenously according to (15) with the production level in the medical R&D sector being determined by the profits accruing in the health care sector which are assumed to be entirely devoted to the purchase of new technology:

$$p_M(t)G(A_M(t), K_M(t), L_M(t)) = V_H(t). \tag{17}$$

We motivate the full extraction by R&D firms of the competitive rents within the health care sector by way of (perfect) quality competition between health care providers. In order to attract demand from patients (or their referring physicians) hospitals need to provide services based on the state-of-the art technology. This in turn motivates them to purchase even incrementally better technologies up to the point that all profit is extracted. Chandra et al. (2016) provide recent evidence for precisely this form of quality competition in the US health care sector.[11]

2.4 Health Insurance, Social Security and Accidental Bequests

We assume that the government and/or a third-party payer (e.g. a health insurer) raise taxes (or contribution rates, e.g. insurance premiums) for the purpose of co-financing health care at the rate $1-\phi(a,t)$ and paying out transfer payments $\pi(a,t)$. In our numerical analysis we will assume $\pi(a,t)$ to be pension benefits, implying that

$$\pi(a,t)=\begin{cases}0 \Leftrightarrow a<a_R\\ \pi(t)\geq 0 \Leftrightarrow a\geq a_R\end{cases}$$

with $\pi(t)$ a uniform pension benefit at time t and a_R the retirement age. In such a setting we also have

$$l(a,t)=\begin{cases}l(a)\geq 0 \Leftrightarrow a<a_R\\ 0 \Leftrightarrow a\geq a_R\end{cases}.$$

Likewise, $\tau(a,t)$ are age-specific taxes set at levels that ensure the government's and private health insurer's budget balance $\Upsilon(t)=\Pi(t)+p_H(t)\int_0^\omega[1-\phi(a,t)]\,h(a,t)S(a,t)B(t-a)da$. Further details on the modeling of health insurance and social insurance are provided in Section.3.1 on the calibration of the model.

Finally, we assume that

$$s(t)=\frac{\Upsilon_B(t)}{N(t)}, \tag{18}$$

where

$$\Upsilon_B(t)=\int_0^\omega \mu(a,t)k(a,t)N(a,t)da \tag{19}$$

are total accidental bequests.[12]

[11] Of course, the notion of perfect competition within the health care sector amounts to a stylisation. We opt for this simplification (i) as it is perfectly apt to reproduce the observed patterns of data, in particular, the price for medical care, overall health expenditure, and the rate of medical innovation; and (ii) as we do not see any reasons for why a more parsimonious model of imperfect competition should give rise to any different patterns of the relevant data.

[12] In order to ease on notation, we will subsequently refer to the shortcut $\mu(a,t)$ for $\mu(a,h(a,t),M(t))$.

2.5 Individual Life-Cycle Optimum

In Appendix 6.1 we show that the solution to the individual life-cycle problem is given by the following two sets of conditions

$$\begin{aligned} & \frac{u_c\left(c\left(a,t\right)\right)}{\exp\left\{-\int_a^{\widehat{a}}\left[\rho+\mu\left(\widehat{\widehat{a}},t+\widehat{\widehat{a}}-a\right)\right]d\widehat{\widehat{a}}\right\}u_c\left(c\left(\widehat{a},t+\widehat{a}-a\right)\right)} \\ = & \exp\left[\int_a^{\widehat{a}} r\left(t+\widehat{\widehat{a}}-a\right)d\widehat{\widehat{a}}\right], \qquad (20) \\ \psi\left(a,t\right) = & \frac{-\phi\left(a,t\right)p_H\left(t\right)}{\mu_h\left(a,t\right)} \quad \forall\left(a,t\right), \qquad (21) \end{aligned}$$

describing the optimal pattern of consumption $c(a,t)$ and the demand for health care $h(a,t)$, respectively, of an individual aged a at time t. Condition (20) is the well-known Euler equation, requiring that the marginal rate of intertemporal substitution between consumption at any two ages/years (a,t) and $(\widehat{a}, t+\widehat{a}-a)$ equals the compound interest. Note that in the absence of annuities, the uninsured mortality risk can be interpreted as an additional factor of discounting, implying an effective discount rate $\rho+\mu(a,t)$ at any (a,t). Rising mortality then implies a downward drag on consumption toward the end of life.

Condition (21) requires that at each (a,t) the private value of life, i.e. the willingness to pay for survival, $\psi(a,t)$, equals the price of survival, $-\phi(a,t)\,p_H(t)/\mu_h(a,t)$. Here, the consumer price for health care, $\phi(a,t)\,p_H(t)$, is converted into a price of survival by weighting with the number of units of health care required for a unit reduction in mortality, $[\mu_h(a,t)]^{-1}$. The private value of life is defined by

$$\psi\left(a,t\right) := \int_a^{\omega} v\left(\widehat{a},t+\widehat{a}-a\right)R\left(\widehat{a},a\right)d\widehat{a}, \qquad (22)$$

with

$$v\left(a,t\right) := \frac{u(c\left(a,t\right))}{u_c\left(\cdot\right)}, \qquad (23)$$

and

$$R\left(\widehat{a},a\right) := \exp\left[-\int_a^{\widehat{a}} r\left(t+\widehat{\widehat{a}}-a\right)d\widehat{\widehat{a}}\right], \qquad (24)$$

and amounts to the discounted stream of consumer surplus, $v = u(\cdot)/u_c(\cdot)$ taken over the expected remaining life-course $[a, \omega]$.[13] It is readily checked that the value of life at each (a, t) increases (i) with the level of the individual's consumption and, thus, the individual's income, and (ii) with the state of the medical technology, the latter effect arising as technology-induced mortality reductions, $\mu_M(\widehat{a}, t + \widehat{a} - a) < 0$, cause over the remaining life-course $\widehat{a} \in (a, \omega)$ a reallocation of consumption toward these later life-years. The price of survival (a, t), in turn, decreases (i) with health insurance coverage, $1 - \phi(a, t)$, at (a, t), and (ii) with the state of the medical technology, given that the latter raises the effectiveness of health care, $\mu_{hM}(a, t) < 0$. Thus, intuitively, the demand for medical care will - ceteris paribus - increase with income, with the extent of health insurance, and with the state of the medical technology. While price and income effects modify these partial equilibrium impacts, our numerical analysis shows that these same three drivers of the (individual and aggregate) demand for health care are operative in general equilibrium.

2.6 General Equilibrium

Perfectly competitive firms in the three sectors $j = Y, H, M$ choose labour $L_j(t)$ and capital $K_j(t)$ so as to maximize their respective period profit (12), (14) and (16). The six first-order conditions determine the six (sector-specific) factor demand functions, depending on the set of prices $\{r(t), w(t), p_H(t), p_M(t)\}$.[14] Likewise, we obtain the age-specific demand for consumption goods $c(a, t)$ and health care $h(a, t)$ from the set of first-order conditions (20) and (21) of the individual life-cycle problem. The age profile of individual wealth $k(a, t)$ then follows implicitly from the life-cycle budget constraint (3). Aggregating across the age-groups alive at each point in time t according to (7)-(10) gives us the aggregate supply of capital $K(t)$ and labour $L(t)$, as well as the aggregate demand for consumption $C(t)$ and health care $H(t)$. The general equilibrium

[13] The VOL as we calculate it here differs from the typical representation of the value of a statistical life as e.g. in Shepard and Zeckhauser (1984), Rosen (1988), or Murphy and Topel (2006) in as far as (i) the discount factor does not include the mortality rate; and (ii) the VOL does not include the current change to the individual's wealth, $lw - c - h - \tau + \pi + s$. Both of these features are due to the absence of an annuity market.

[14] With appropriate Inada conditions on the production functions, we always have an interior allocation with $L_M(t) = L(t) - L_Y(t) - L_H(t) \in (0, L(t))$ and $K_M(t) = K(t) - K_Y(t) - K_H(t) \in (0, K(t))$.

characterization of the economy is completed by the set of five market clearing conditions

$$\begin{aligned} L_Y(t) + L_H(t) + L_M(t) &= L(t) \\ K_Y(t) + K_H(t) + K_M(t) &= K(t) \\ Y(A_Y(t), K_Y(t), L_Y(t)) &= C(t) + \dot{K}(t) + \delta K(t) \\ F(A_H(t), K_H(t), L_H(t)) &= H(t) \\ p_M(t) G(A_M(t), K_M(t), L_M(t)) &= V_H(t) \end{aligned}$$

corresponding to the labour market, the capital market, the market for final goods, the market for health care and the market for medical innovation, respectively. From these, we then obtain a set of equilibrium prices $\{r^*(t), w^*(t), p_H^*(t), p_M^*(t)\}$ and the level of net capital accumulation $\dot{K}(t)$. Appendix 6.2 provides a more detailed characterization based on the Cobb-Douglas production functions specified in (11), (13) and (15), respectively.

3 Numerical Analysis: Calibration and Benchmark

Following a description of our numerical analysis, we present the outcomes for a benchmark scenario that features a realistic economy calibrated to US data from 1960 to 2005 with respect to the macroeconomic development in this period, the institutional changes as well as the life-cycle profiles (see Section 3.3). We subsequently use this to examine the role of health insurance in a number of counterfactual numerical experiments. Technical information on the numerical solution method is provided in Appendix 6.3.

3.1 Specification and Calibration

The main components of our numerical model are specified as follows.

Demography

Individuals enter the model economy at age 20 and can reach a maximum age of 100 with model time progressing in single years.[15] In our model, a "birth" at age 20 implies a maximum age $\omega = 80$.

[15] We follow the bulk of the literature and neglect life-cycle decisions during childhood.

Population dynamics are partly endogenous due to mortality that is determined within the model and partly exogenous due to a fixed growth rate schedule of "births" $\nu(t)$. The number of births at time t is given by

$$B(t) = B_0 \exp\left[\int_0^t \nu(\hat{t})d\hat{t}\right], B_0 > 0.$$

The time-dependence of the growth rate of births will be set (in consideration of the endogenously determined mortality) to match the age-structure of the United States between 1965 and 2005, see Table 2.[16] Due to the exogenous path of births, our results will not be driven by changing birth numbers across the experiments. This notwithstanding, with the bulk of mortality lying beyond the fecund years since at least the second half of the 20th century, we do not expect the assumption of an exogenous flow of births to have any great impact on our results.

Mortality

The force of mortality $\mu(a,t) = \mu\left(h\left(a,t\right), M\left(t\right)\right)$ is endogenously determined in the model and depends on health care, $h\left(a,t\right)$, as a decision variable, and on the level of medical technology, $M\left(t\right)$. Adapting Hall and Jones (2007), we formulate

$$\mu(a,t) = \eta(a)\left(h(a,t)\right)^{\kappa(a)M(t)}, \tag{25}$$

where $\eta(a) > 0$ and $\kappa(a) < 0$ are parametric functions that reflect the age-specific effectiveness of health care.[17] We choose $\kappa(a)M(t = 2000)$ to be in the range of age-specific elasticities of mortality with respect to health care utilization for the year 2000, as reported in Hall and Jones (2007). The term $\eta(a)$ is then determined such that the age pattern of optimal health expenditure and the endogenous level of medical technology yield the empirically observed mortality pattern for a given year.[18] For further detail on the effectiveness of health care spending in lowering mortality consult Appendix 6.4.

[16] Note that our primary measures of age-structure, namely the population share of individuals aged 65 or older, as well as the employment-population ratio refer to the population aged 20 or older in the denominator. The data used in Table 2 hence refers to the population without individuals aged less than 20.

[17] The functional form of $\mu(a,t)$ fulfills the properties of the mortality function outlined in section 2.1 within the relevant value space of h, κ and M.

[18] We use the year 1965, representing the beginning of the time period under consideration, to calibrate $\eta(a)$. The mortality rate for the US in 1965 is taken from the Human Mortality Database.

Utility

We assume instantaneous utility to be given by

$$u(a,t) = b + \frac{c(a,t)^{1-\sigma}}{1-\sigma},$$

where we choose the inverse of the elasticity of intertemporal substitution to be $\sigma = 1.2$ which is within the range of the empirically consistent values suggested by Chetty (2006). Setting $b = 8.4$ then guarantees that $u(a,t) \geq 0$ throughout and generates an average value of life that lies within the range of plausible estimates, as suggested in Viscusi and Aldy (2003) and documented in Table 2. Moreover, we assume a rate of time preference $\rho = 0.03$.

Finally, we impose a minimum consumption level equal to the social security benefit at a given point in time. We do so to avoid negative asset holdings at old age, as would otherwise result from ex-ante optimization.[19] Given that retirees cannot usually loan against future pension income and given that individuals are downspending their assets in old age (as they do within our model) the minimum consumption constraint is plausible.

Effective Labour Supply and Income

Following Frankovic et al. (2017), we proxy the effective supply of labour $l(a)$ by an age-specific income schedule constructed from 2003 earnings data, as contained in the Current Population Survey (CPS) provided by the Bureau of Labor Statistics (BLS), and rescaled such that the employment-population ratio $L(t)/N(t)$ matches the empirical value of 62% for the US in 2003 as reported by the BLS. We assume that the age-specific labor supply is constant throughout the whole time horizon with GDP per capita growth as specified in the next subsection. Individuals at the age 65 or older are assumed to have no income from labour but receive a fixed social security pension for the remainder of their lifetime, as detailed further on below.

[19] Individuals choose old-age consumption at the beginning of their life, attaching a low probability to reaching very high ages. Consumption allocated to these ages (in the absence of a minimum consumption level) is thus very low and can fall below the social security income, such that it is optimal to pay back debt (accumulated to finance consumption at earlier ages) at very high ages with excess social security income.

Production

Following the bulk of the literature, we set the elasticity of capital in final goods production (11) to $\alpha = 1/3$. In regard to productivity growth we assume that $A_Y(t)$ grows at a rate of 1.45% per year, such that the GDP per capita is growing in line with the data.[20] For the production elasticity of capital in the production of health care (13) we take an estimate from Acemoglu and Guerrieri (2008) and set $\beta_1 = 0.2$. We then choose $\beta_2 = 0.78$, such that (i) profits accrue in the health care sector and (ii) the medical R&D share in total GDP lies within the range of empirical data for the given time period, see Table 2. Total factor productivity in the medical sector, $A_H(t)$, is assumed to grow at a rate of 0.5%, reflecting the relative slow productivity growth within labor-intensive sectors.[21] For the production of medical R&D according to (15) we assume $\gamma = 0.34$, following the capital elasticity quoted in Acemoglu and Guerrieri (2008) for the category of professional and scientific services. Total factor productivity in the R&D sector $A_M = 0.35$ is assumed to be constant and is chosen such that the growth rate of the annual R&D output $\ddot{M}(t) := d\dot{M}(t)/dt$, is in accordance with the growth rate of medical patents, as provided by the US Patent Office, see Table 2. Finally, we assume a rate of capital depreciation equal to $\delta = 0.05$.

In our calibration we aim to match the increase in health expenditures and the health share of GDP, the data on which is taken from the National Health Expenditure Tables provided by the National Health Accounts (NHA).[22] Importantly, however, we do not directly target these variables in the model parametrization but focus on the calibration of the drivers of health care spending, namely the rate of growth of $M(t)$, as described above, as well as the insurance and income elasticity to be discussed further on below.

Health Insurance and Social Security

Health expenditures are subsidized through two different types of funds: (a) private health insurance with coinsurance rate $\phi_P(a, t)$ and (b) public insurance provided by Medicare, Medicaid and other

[20] As a data source we use the "Real gross domestic product per capita" as provided by the Federal Reserve Bank of St. Louis. Note, however, that $A_Y(t)$ does not determine GDP per capita growth alone, with the evolution of demography, medical technology, health expenditures and other factors also playing a role.

[21] This choice of value is in line with Faere et al. (1997) and Spitalnic et al. (2016) who measure productivity growth in the US health care sector based on the quantity rather than the quality of services and find average productivity growth rates of 0.1-0.7 %. While medical progress in the sense of better health and mortality outcomes is measured by $M(t)$, the measure of increased quantity-related productivity is a good proxy for A_H.

[22] All dollar values are to be understood as constant 2009 USD.

public programmes. We assume that Medicare is only available to the elderly (after the mandatory retirement age $a_R = 65$) with coinsurance rate $\phi_{MC}(a,t)$ and Medicaid only to those of working age ($a < a_R$) with a coinsurance rate $\phi_{MA}(a,t)$. The remaining public programmes are assumed to be available to all age-groups at a coinsurance rate $\phi_{RP}(a,t)$. We use data on health insurance coverage in the US from from the National Center for Health Statistics (NCHS). The NCHS reports sources of payments for health care among the young (<65 years old) and the elderly, providing information on the proportions of total health expenditures that were paid for out-of-pocket (OOP) and through private insurance, Medicare, Medicaid and other public insurance programmes, respectively.[23]

Figure 2 shows the evolution of insurance coverage from 1965 to 2005 for the young (<65 years) and the elderly in the US. In our simulation, we interpret the shares of each type of fund as exogenous age- and time-dependent health care subsidies.

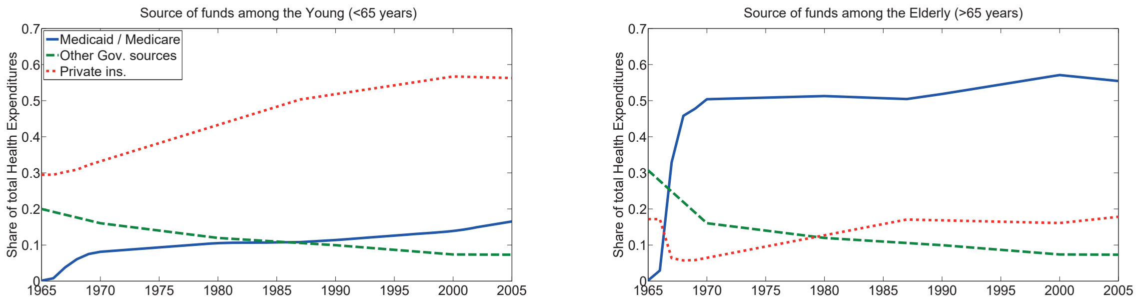

Figure 2: Share of total health expenditures over time covered by Medicaid (for the young) and Medicare (for the elderly), by other government programmes, and by private insurance for the young (left) and for the elderly(right).

Private health insurance is financed through a "risk-adequate" premium equal to the expected health expenditure, $p_H(t)h^*(a,t)$, covered by the insurance for an individual at a given time and age. It is thus given by $\tau_P = [1 - \phi_P(a,t)]\, p_H(t)h^*(a,t)$. As described above, we set $\phi_P(a,t)$ equal to the share of expenditures paid for by private insurance, where we obtain different co-payment rates among the young and the elderly in accordance with the data. Analogously, we can construct $\phi_{MC}(a,t)$, $\phi_{MA}(a,t)$ and $\phi_{RP}(a,t)$.[24] All public programs are financed through payroll taxes, with

[23] We use the 1976-1977 "Health" report by the NCHS (Table 149) to obtain data from 1966 to 1975, as well as the 2015 "Health" report (Table 98) for the years 1987, 1997, 2000 and 2012 to identify the share of health expenditures funded out-of-pocket, by public programs and by private health insurance for the young and the elderly (65 and above), respectively. We then identify the share of government funds devoted to programmes other than Medicare and Medicaid from the 2010 "Health" report (Table 126) for 1960 - 2006. Based on this data and by making the simplifying assumption that Medicaid is utilized only by the young and Medicaid only by the elderly we can construct the time-series in Figure 2. All NCHS "Health" reports are available at https://www.cdc.gov/nchs/hus/previous.htm.

[24] The age-specific total co-insurance rate of health expenditures exhibits a small discontinuity at age 65 when using

the rates $\hat{\tau}_{MC}$, $\hat{\tau}_{MA}$ and $\hat{\tau}_{RP}$ being endogenously determined such that the budget constraints

$$\begin{aligned}\int_{a_R}^{\omega} [1-\phi_{MC}(a,t)]\, p_H(t)\, h(a,t)N(a,t)da &= \hat{\tau}_{MC}(t)w(t)L(t),\\ \int_{0}^{a_R} [1-\phi_{MA}(a,t)]\, p_H(t)\, h(a,t)N(a,t)da &= \hat{\tau}_{MA}(t)w(t)L(t),\\ \int_{0}^{\omega} [1-\phi_{RP}(a,t)]\, p_H(t)\, h(a,t)N(a,t)da &= \hat{\tau}_{RP}(t)w(t)L(t)\end{aligned}$$

hold, where $1-\phi_x(a,t)$ is the share of health expenditures paid by program x and $\hat{\tau}_x$ is the according payroll tax.

Social security, received by retirees, is financed through a payroll tax which is determined endogenously from the social security budget constraint:

$$\int_{a_R}^{\omega} \pi(a,t)N(a,t)da = \hat{\tau}_{\Pi}(t)w(t)L(t),$$

where $\pi(a,t)$ is the social security pension and $\hat{\tau}_{\Pi}$ the payroll tax devoted to social security. We assume social security benefits to be exogenous and use the Annual Statistical Supplement provided by the Social Security Agency that provides the average monthly social security income for the years 1960-2014 (see Figure 3).

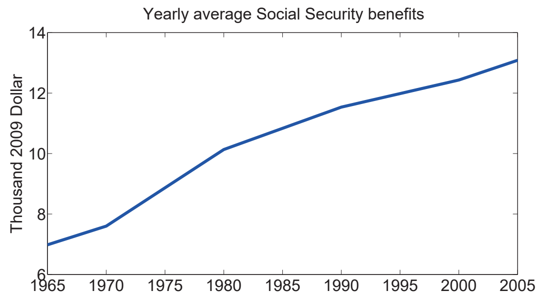

Figure 3: Yearly average Social Security benefits from 1965 to 2005 in 2009 US Dollars.

Overview of Functional Forms and Parameters

Table 1 summarizes the most important parameters we are employing. Table 2 provides an overview on the calibration strategy and presents the match of several key target variables.

this calibration strategy. We smooth the jump after retirement by linearly adapting the private insurance levels of individuals after retirement.

Parameter & Functional Forms	Description
$\omega = 80$	life span
$t_0 = 1950$	entry time of focal cohort
$\rho = 3\%$	pure rate of time preference
$\sigma = 1.2$	inverse elasticity of intertemporal substitution
$b = 8.4$	constant utility of being alive
$a_R = 65$	mandatory retirement age
$\delta = 5\%$	rate of depreciation
$\alpha = 0.33$	elasticity of capital in Y
$\beta_1 = 0.2$	elasticity of capital in F
$\beta_2 = 0.78$	elasticity of labour in F
$\gamma = 0.33$	elasticity of capital in G

Table 1: Model parameters

Parameter	Target	Match
$\eta(a)$	Mortality profile	Perfect match for 1965 by construction Match for other years see life-expectancy
$M(t)$	Life-expectancy	Model: 72.5 (1965), 78 (2000) Data : 72.6 (1965), 77.9 (2000)
$\nu(t)$	Share of Elderly	Model: 15.2% (1965), 17.8 % (2000) Data : 14.8 % (1965), 17.3 % (2000)
σ	Income elasticity of health care spending	Income elas. of 0.2 (micro) and 0.9 (macro)
b	Value of life	Model: 2 Mio. (1965), 6 Mio. (2000) Data : 7 Mio (2000)
$l(a)$	Income schedule employment-population ratio	Perfect match by construction 2003: Model: 63 %, Data: 62 %
$A_Y(t)$	GDP per capita	see Figure 4
A_M	Growth rate of $\dot{M}(t)$	Model: 4.5 %, Data: 4.2 %
β_2	Medical R&D share of GDP	Model: 0.08 % (1965), 0.34 % (2000) Data : 0.06 % (1960), 0.5 % (2000)
$\phi(a,t)$	Avg. OOP expenditure share Medicare share of GDP	see Figure 5 see Figure 5

Table 2: Targets to match

3.2 Determinants of Health Care Spending

In order to appreciate the results of our numerical analysis it is helpful to consider how health insurance, income and medical technology are affecting health care spending in isolation. Specifically, we calculate the arc elasticity of health care expenditure $p_H H$ with respect to a ceteris paribus variation between the years 2005 and 1965 in the rate of coinsurance ϕ, per capita income y, and the state of medical technology M, respectively The arc elasticity is defined as

$$\epsilon\left(p_H H, x, 1965, 2005\right) := \frac{\left((p_H H)_{2005} - (p_H H)_{1965}\right) / \left((p_H H)_{2005} + (p_H H)_{1965}\right)}{\left(x_{2005} - x_{1965}\right) / \left(x_{2005} + x_{1965}\right)}, \quad x = \phi, y, M$$

with $\frac{(p_H H)_{2005} - (p_H H)_{1965}}{\left((p_H H)_{2005} + (p_H H)_{1965}\right)/2}$ and $\frac{x_{2005} - x_{1965}}{(x_{2005} + x_{1965})/2}$ denoting the percentage change in $p_H H$ and $x = \phi, y, M$, respectively, averaged over the time period 1965-2005. Based on our benchmark simulation (see Section 3.3), we obtain the values summarized in Table 3. Here, the forward values refer to a ceteris paribus variation in x from the 1965 to the respective 2005 values, taking the 1965 state of the economy as a starting point, whereas the backward values refer to a variation in x from the 2005 to the respective 1965 values, taking the 2005 state of the economy as a starting point.

Table 3: Arc elasticities of health care spending

	Forward elasticity	Backward elasticity
Insurance: $x = \phi$	-0.92	-0.83
Income: $x = y$	0.93	0.90
Medical Technology: $x = M$	0.64	0.51

The values we find for the insurance elasticity are well in line with recent microeconomic evidence by Kowalski (2015) and relatively close to the estimates in Eichner (1998) and Fonseca et al. (2013) who find a spending elasticity of around -0.6.[25] The values we obtain for the income elasticity lie within the range of estimates based on macroeconomic data, as reported in Getzen (2000), and the more recent estimates provided by Acemoglu et al. (2013) and Murthy and Ketenci (2017).[26]

[25] This contrasts against the spending elasticity estimates of -0.2 to -0.3 from the original RAND health insurance experiment (Manning et al. 1987). As Kowalski (2015) point out, the original RAND estimate does not take into account the stoploss mechanism embedded into most health insurance schemes, biasing the elasticity downwards (in absolute terms.) In fact, Kowalski (2015) is able to closely reproduce the RAND estimate when stoploss is not accounted for.

More generally, no clear consensus has been reached yet about the most plausible estimates of the spending elasticity. This is not the least because some of the economic, technical and data problems involved with the estimation of non-linear insurance contracts are still waiting to be fully resolved (Aron-Dine et al. 2013).

[26] One issue of note is that our forward elasticity of around 0.93 implicitly incorporates the increase in the price

Finally, the spending elasticity with respect to medical progress is reasonably well in line with recent estimates by Murthy and Ketenci (2017).

While these elasticities are suggestive of the impacts of insurance, income and medical technology in isolation, it is well known that their impacts are magnified due to the presence of complementarities (see e.g. Fonseca et al. 2013). A formal derivation of the spending elasticities and the complementary relationships at the individual level can be found in Appendix 6.4.

3.3 Benchmark

In this section, we will present the benchmark economy over the period 1960-2005 and illustrate the model fit. The benchmark allocation is depicted by blue, solid line plots throughout all figures. We confine our presentation to the macroeconomy. Some detail on the individual life-cycle outcomes is contained in Appendix 6.5.

Figure 4 plots the evolution of the GDP and health expenditures per capita as well as the GDP health share against the US data, as depicted by the asterisks. Reasonably well in line with the data, GDP per capita increases by a factor of about 2.8 and health expenditures by a factor of 8.5 over the time span 1960-2005.[27] The two developments imply an about three-fold increase of the health expenditure share of GDP over the 45 years under consideration.

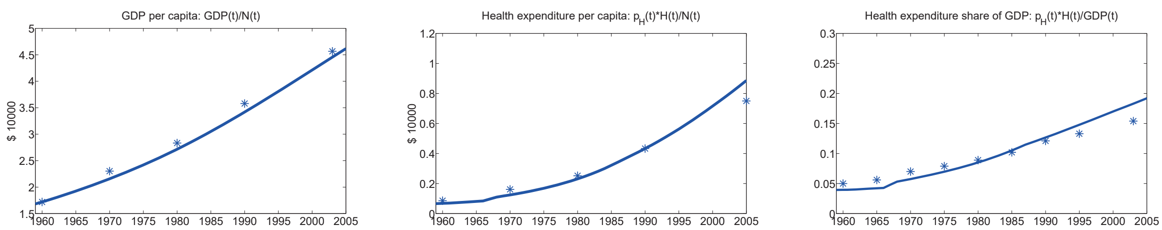

Figure 4: GDP and health expenditures per capita as well as the GDP share in the benchmark scenario (blue, solid line) and data (asterisks)

While the increase in GDP is predominantly driven by the exogenous growth of total factor

of health care caused by productivity increase in the manufacturing sector a la Baumol (1967). If we keep the price for health care fixed and evaluate the impact of a ceteris paribus increase in income, we obtain an income elasticity of merely 0.2. Both values can be reconciled with empirical evidence. Getzen (2000) points out that studies on individual-level data find income elasticities of health expenditures ranging between 0 to 0.7, whereas estimates based on regional and national level range from 0.5 to 1.5. Only the latter group of studies, however, measures (implicitly) the Baumol effects.

[27] We overestimate the health expenditure growth in the 1990s. In this period, health maintenance organizations caused a temporary slowdown of expenditure growth (Chernew and Newhouse, 2011), a development that is not tracked in our model.

productivity in the production sector, the increase in health expenditures is driven by several exogenous trends: insurance expansion, the expansion in social security and productivity-driven income growth, as well as by endogenous medical progress (and thus a shift from consumption to medical expenses, see Frankovic et al. 2017). Figure 5 illustrates the increase in the state of medical technology. While it is difficult to compare $M(t)$ with a real-world measure we can compare the growth rate of $\dot{M}$ (hence $\ddot{M}$) with the growth rate of medical patents over the time span 1965-2005 in the US. Our simulation yields a yearly increase of $\dot{M}$ of 4.5%, while the number of patents has increased by about 4.2% per year.[28] Note, that we do not directly target the development of health expenditures over time in our calibration. Instead we focus on calibrating the role of medical technology through the growth rate of $\dot{M}$, as well as the contribution of insurance and income through empirically valid elasticities of health care spending. In combination, these trends yield an increase in health expenditure that is well in line with the data, implying that our model predicts quite well the outcome variable of interest.

As a result of medical progress and a greater utilization of health care, life expectancy rises, albeit not quite at the same pace as in the empirical data. This is likely due to the fact that not all reductions in mortality can be attributed to health care but changes in lifestyle and the living environment played a role as well. Figure 5 also depicts the Medicare expenditure share of the GDP as well as the average share of out-of-pocket expenditures over the time span 1965-2005. While not targeting these model outcomes directly in our calibration, the exogenous coinsurance rates result in a good match of these variables in the simulation.[29]

The growth of the health care sector has important implications for the macroeconomy. We observe in Figure 6 that the employment shares reflect the shift of the GDP towards the health care sector.[30] Employment in the medical R&D sector increases, too, as its size depends directly on the size of the health care sector [see equation (17)]. The market interest rate, $r(t)$, is endogenously

[28] We calculate the number of new medical patents based on U.S. Patent Statistics Chart, indicator "Utility Patent Grants, U.S. Origin", as provided by the U.S. Patent and Trademark Office, and on estimates about the share of medical patents since 1965, as provided by Jones (2016).

[29] Recall Section 3.1 for a description of how we construct the co-insurance rates.

[30] Note that the employment shares are considerably larger than those reported by the Bureau of Labor Statistics, e.g. 7.5% in 1990 and 9.25% in 2005. Arguably this is due to a broader definition of health care employment implicit in our model. To see this note that the employment share in our model is broadly in line with the health share in GDP, whereas the employment share in the data amounts to just about half the size of the health share in GDP. This is inconsistent with the health care sector being relatively labour intensive and speaks to the fact that the production of health care is associated with significant "non-medical" employment (for e.g. the production of intermediate non-capital inputs toward the production of health care). This "non-medical" employment is counted in our model.

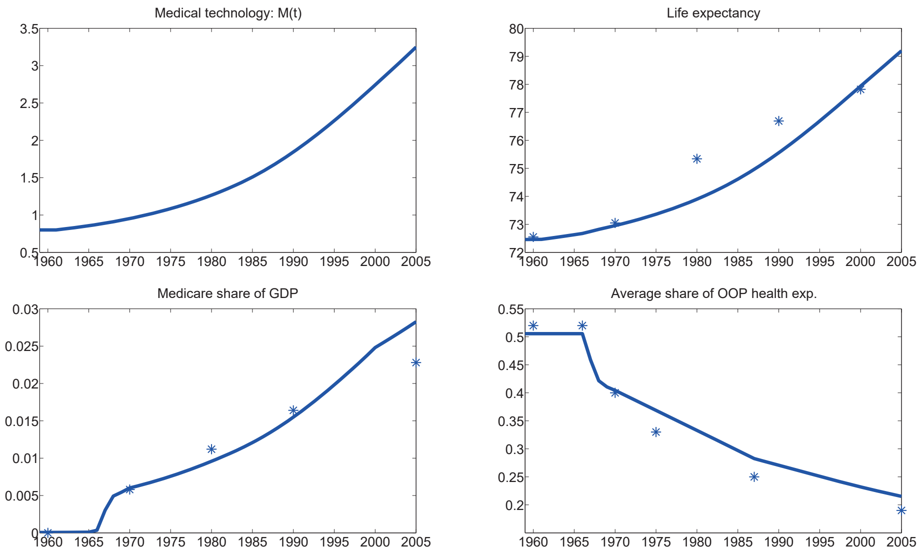

Figure 5: Medical technology, life expectancy, Medicare share of GDP and the average share of out-of-pocket (OOP) health expenditures

determined within the model, and falls over the time period under consideration. While we cannot explain the empirical ups and downs of real returns on capital, we can account for the long-term increase in saving and the consequential decline in the interest rate associated with an ageing population (see e.g. Bloom et al. 2003, De Nardi et al. 2010, Aksoy et al. 2016).

While boosting the supply of capital through the increase in longevity, medical progress also lowers the demand for capital by shifting production into the comparatively labour-intensive health care sector. The resulting excess supply of capital is, thus, absorbed only through a fall in the interest rate. A more detailed explanation of this mechanism can be found in Frankovic et al. (2017). This trend is further reinforced by the well-known Baumol (1967) effect, where productivity growth in the capital-intensive final goods sector induces a shift of production factors into the more labour-intensive health care sector. The ensuing (relative) scarcity of labour tends to depress the interest rate even further.[31]

Wage growth mainly reflects the increase in productivity, but wages also rise due to the increasing relative scarcity of labour as described above. As the health care sector is comparatively labor-intensive, the rising price for labor overcompensates the falling price for capital and induces a growth of the price of health care over time. In fact, we can compare p_H with the ratio of the med-

[31] See Acemoglu and Guerrieri (2008) for an analytical representation of this mechanism.

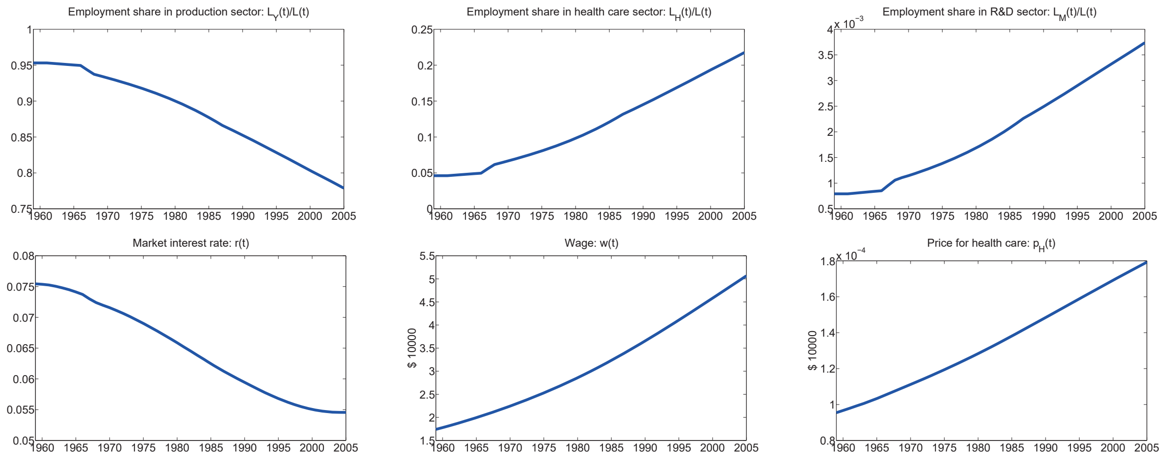

Figure 6: Macro variables in the benchmark scenario

ical price index to the consumption price index (CPI) in the US, as based on data from the Bureau of Economic Analysis (BEA). Over the time span 1980-2000, medical prices have risen 1.6-times faster than the overall CPI according to BEA. This compares quite well to the 1.4-fold increase in p_H over the same time period in the benchmark economy. Hence, while there are additional factors, such as market concentration in the health care sector, that explain the rate of medical price inflation, we would consider sectoral change and the resulting factor price adjustments as one key contributor.

4 Identifying the Impact of Health Insurance on Medical Spending Growth

In order to gain an understanding of the role of health insurance in driving health expenditure growth, we proceed in two steps. First, we carry out a set of relatively simple comparative dynamic simulations in order to quantify the individual contributions of income, insurance and medical progress to medical spending growth, as well as the complementarities involved (see Section 4.1). Second, we study a counterfactual scenario in which the health insurance setting is fixed to the year 1965 in order to trace out the full dynamic impact of the health insurance expansion over the time span 1965-2005 (see Section 4.2). This analysis will explicitly account for the medical progress induced by the expansion of health insurance. We will then employ further counterfactuals to separate the moral hazard impact of insurance expansion from the spending impact of induced medical progress. After studying the welfare impact of the insurance expansion (see Section 4.3) we conclude by assessing the role of income growth as an intervening process (see Section 4.4).

4.1 Contributors to Spending Growth

In order to gain a first impression of the contributions of income, insurance and medical progress to the medical spending growth we consider the following set of (counterfactual) simulations: The baseline is represented by a simulation in which medical technology, age-specific coinsurance rates as well as the income level are all fixed to the level of the year 1965.[32]. Letting, in three separate runs, each of the three factors evolve (up to the year 2005) in the same way as in the benchmark simulation while holding the remaining factors constant at their 1965 levels, we then evaluate the impact on health care expenditures. We also simulate the effect on medical expenditures of two factors evolving jointly along their benchmark trajectories, while keeping the third factor fixed to the 1965 level. Comparing the joint effect against the sum of the individual effects we can quantify the extent of complementarity between the three drivers of expenditure growth. Table 4 summarizes the results, reporting for each of the scenarios the increase in health care spending relative to the 1965 level.

Factor	Increase in health spending
Medical Progress	+120%
Insurance Expansion	+120%
Income Growth	+140%
Medical Progress + Insurance	+330%
Medical Progress + Income	+380%
Income + Insurance	+430%
Benchmark	+850%

Table 4: Increase in health care expenditure relative to its 1965 level

When considered in isolation, medical progress and insurance expansion lead to a sizeable and equal expansion of health care expenditure by 120%, while income growth leads to an expansion by 140%. Summing the three isolated growth trends yields an increase of health expenditure by 380% which explains only about 44% of the increase between 1965 and 2005 that is observed in the benchmark (and data). This highlights the substantial role of complementarities between the three

[32]The population structure as well as the level of social security benefits are also held constant at their 1965 levels.

growth factors, which account for broadly 56% of expenditure growth.[33] This finding is well in line with the earlier analysis by Fonseca et al. (2013) who find that 57.3% of spending growth are attributable to complementarities.[34] Contrasting the combined growth effects against the sum of the respective individual effects shows that the complementarity between insurance and income is strongest. With a combined 430% increase in health care expenditure set against a 260% increase predicted by the summed individual effects, the complementarity between insurance and income triggers an additional 170% increase. This exceeds each of the individual effects and amounts to about 40% of the combined effect. Inducing an additional 120% and 90% of expenditure growth on top of the summed individual effects, the income-medical progress and insurance-medical progress complementarities, respectively, are somewhat smaller but still of a sizable magnitude.

While the analysis so far has been informative about the contribution of the various expenditure drivers, it fails yet to account for the fact that medical progress itself is endogenous. The remainder of the analysis is, thus, seeking to identify the impact of health insurance expansion on health expenditure growth, paying particular attention to induced medical progress, while treating productivity growth as an exogenous background trend.

4.2 Counterfactual: No Insurance Expansion

We now simulate a counterfactual economy in which the insurance expansion from 1965 until 2005 is assumed not to have taken place (shown throughout by the green, dashed plot). Thus, we hold public and private health insurance rates constant from 1965 onwards. Figure 7 shows a much slower growth rate of health expenditure in the counterfactual. A comparison with the benchmark shows that the expansion of health insurance explains about 60% of the spending increase between 1965 and 2005.

This result ties in well with an empirical finding by Finkelstein (2007) on the impact of the introduction of Medicare on health care expenditures. Relative to individual-level studies on the

[33] Strictly speaking the expansion of social security and demographic change would explain some part of the 56% residual, these effects are small, however.

[34] Fonseca et al. (2013) differ in the attribution of expenditure growth to the three individual trends. In their model 29.9% are explained by medical progress, 7.7% are explained by insurance growth and 4.3% are explained by income growth, whereas in our model the respective figures are 14% for the first two factors and 16% for income. One reason for the much stronger contribution of medical progress is likely to lie in the partial equilibrium approach they are taking. As we show in Frankovic et al. (2017), however, the impact of medical progress on expenditure is strongly dampened in general equilibrium, which is the approach we are choosing.

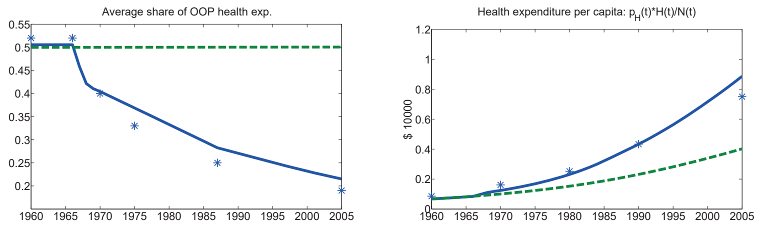

Figure 7: Average share of OOP expenditure and health expenditure per capita in the benchmark (blue, solid) and the counter-factual reflecting constant 1965 insurance level (green, dashed)

consequences of health insurance on medical spending (such as the RAND health insurance experiment), she finds a six-time larger effect when also taking into account aggregate effects of the insurance expansion, such as the adoption of medical technology and increased hospital market entries. Extrapolating the insurance elasticity of health spending found for Medicare to the overall reduction of out-of-pocket expenditures observed in the US from 1950-1990, she finds that the insurance expansion over this time period can account for approximately 50% of the overall increase in US medical spending.

Figure 8 reveals a much slower progress of medical technology in the counterfactual. This is because the absence of large-scale health insurance programs leads to a smaller health care market. The lower profits in the health care sector then translate into lower R&D expenditures as compared to the benchmark scenario. Our analysis suggests that the expansion of health insurance led to a 41% increase in the growth rate of medical progress. This is well in line with the empirical results by Clemens (2013) who finds that the introduction of Medicare/Medicaid induced a 33% increase in the growth rate of medical patents. The additional boost to medical R&D in our model can be attributed to the concomitant expansion of private health insurance coverage.

The expansion of health care coverage in the benchmark scenario as opposed to the counterfactual, thus, spurs the growth of health care demand and consequently health care expenditure through the following channels: a direct one, transmitted through spending increases in the presence of lower co-payments; and an indirect one, transmitted through faster growth in medical R&D and, thus, through faster medical progress which, in turn, leads to an additional boost to the demand for health care. As we have seen already, the complementarities between the expansion of health insurance and income growth as well as medical progress strongly contribute to health care expenditure. Notably, two of the three complementarities between the growth factors are active

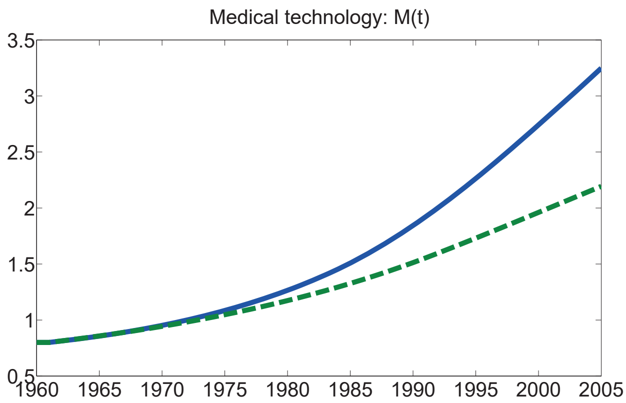

Figure 8: Medical Technology in the benchmark (blue, solid) and the counter-factual reflecting constant 1965 insurance level (green, dashed)

only in the presence of an expanding health insurance, implying a magnified impact of income growth on health care expenditure in the benchmark relative to the counterfactual scenario.

The impact of the insurance expansion on health care expenditure is mirrored by its converse impact on consumption per capita (some comments on the individual life-cycle outcomes are, again, contained in Appendix 6.5). As Figure 9 illustrates, consumption per capita grows at a considerably higher rate in the counterfactual. Notably, the insurance expansion in the benchmark stifles consumption per capita not only by inducing a reallocation of individual expenditures to health care but also by boosting the capital accumulation: Here, the more pronounced increase in life expectancy from 72.5 years in 1965 to 78 years in 2000 in the benchmark as opposed to only 75.7 years in the counterfactual induces a reallocation of expenditures to higher ages and, consequently, to additional savings. Surprisingly perhaps, the expansion of health insurance depresses the average value of life. This finding can be interpreted in two ways: With the value of life being defined by the discounted stream of consumer surplus over the remaining life-cycle [see (22)-(24)] the higher rate of growth of the value of life in the counterfactual simply reflects stronger consumption growth. At the same time, the optimal choice of health care implies that the value of life equals the effective price of survival [see (21)]. As it turns out, the latter is declining on average both due the ongoing reduction in co-payments and due to increasing effectiveness of health care, these two trends overcompensating a concomitant increase in the price for health care.

Finally, Figure 10 illustrates the impact of the health insurance expansion on prices. The much smaller growth in the health care sector in the counterfactual scenario is reflected in a lower rate

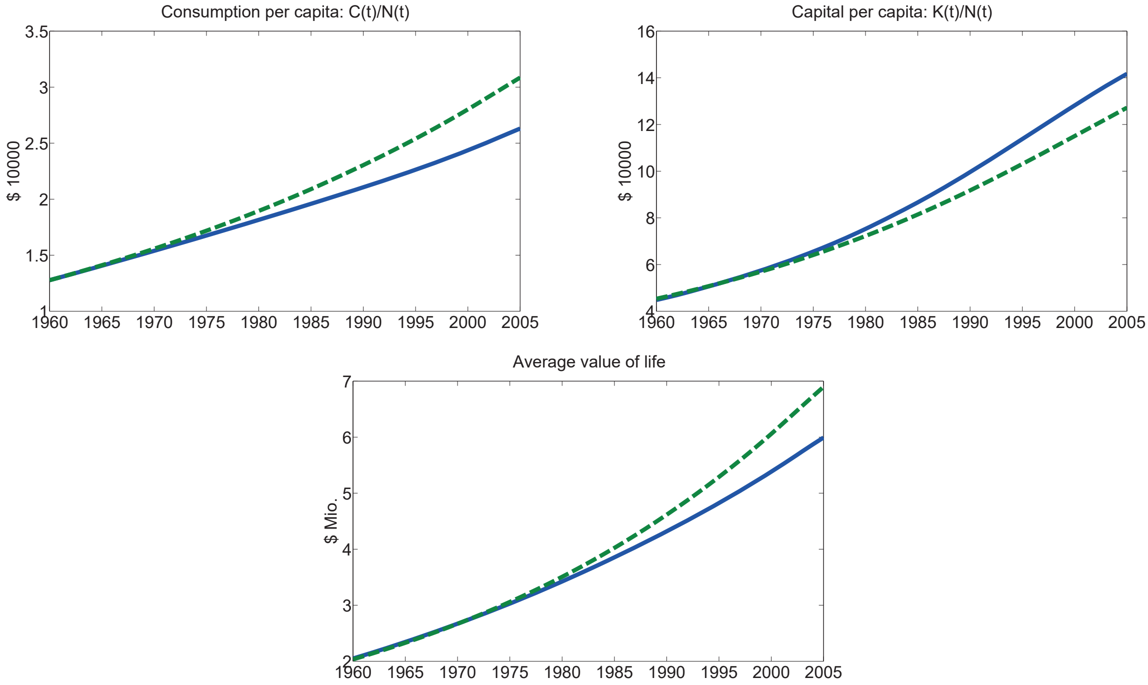

Figure 9: Per capita values of consumption and capital and the population-weighted average value of life in the benchmark (blue, solid) and the counter-factual (green, dashed)

of wage growth and a lower rate of health care price inflation. The effects are modest, however, in relation to the increase driven by productivity growth in final goods production. The impact of health insurance expansion on the development of the interest rate is more pronounced, the interest rate in the counterfactual declining at a much lower rate to a level that in 2005 is almost one percentage point higher. This wedge is reflecting the gap in life expectancy and, thus, the lower degree of capital accumulation in the counterfactual scenario.

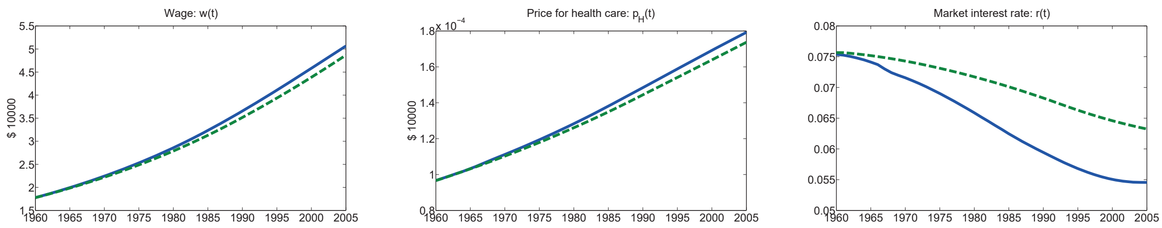

Figure 10: Prices in the benchmark (blue, solid) and the counter-factual reflecting constant 1965 insurance level (green, dashed)

4.2.1 Disentangling Moral Hazard and Induced Innovation

It is instructive to disentangle the direct impact of insurance on health care spending, which can be broadly summarized as a moral hazard effect,[35] from the spending impact that arises through the stimulation of medical innovation. In order to separate the two channels we now simulate the effect of the insurance expansion in the realistic benchmark environment while the state of technology is assumed to develop according to the main counterfactual. This scenario, depicting the moral hazard channel, is illustrated by the red, dotted plot in Figure 11. The resulting trajectory of health expenditure shows that moral hazard accounts for a large part of the increase in expenditures from counterfactual to benchmark. The remainder is explained by induced medical progress which we have switched off in this scenario. The cyan dash-dotted plot shows the "complementary" counterfactual simulation in which insurance is fixed to its 1965 level but medical technology evolves according to the benchmark scenario. The distance between the cyan dash-dotted and the green dashed plot, therefore, measures the contribution of induced medical progress in a direct way. Overall, we find that about 81% of the additional spending in 2005 that is due to the expansion of health insurance can be attributed to moral hazard, whereas the remaining 19% can be attributed to induced medical progress.[36],[37]

We conclude by pointing out that while moral hazard as opposed to induced medical progress explains the majority of the spending increase, the opposite is true in respect to the benefits in terms of life-years gained. Recall here that the expansion of health insurance leads to an additional 2.3 years of life expectancy in the year 2000 (78 years in the benchmark scenario as opposed to 75.7 in the main counterfactual). We find that 2 years of this increase are due to induced-medical

[35] Here, moral hazard is to be understood in a macro-economic sense, involving price adjustments as well as adjustments in the age structure of the population.

[36] The relatively large direct effect should not be interpreted in a way that insurance dominates medical progress as a driver of health expenditure. It should be borne in mind that the reference in this simulation is the *additional* medical progress induced by the health insurance expansion. This is especially important, when it comes to the complementarities over time: When assessing the direct impact of insurance expansion (red-dotted plots), medical progress is assumed to develop according to the main counterfactual, where the rate of progress is lower but nevertheless positive. Thus, complementarities (with both factors emerging in lockstep) are active along all three margins of the insurance-income-medical-progress nexus. In contrast, when assessing the impact through induced medical progress (cyan dash-dotted plots), there is no development over time in respect to insurance coverage. Thus, the only active complementarity is between medical progress and income. This speaks to a much weaker dynamic effect.

[37] With induced medical progress explaining 19% of the spending increase from the insurance expansion and this, in turn, explaining 60% of the overall spending increase, we find that insurance-induced medical progress explains about 11.5% of the overall increase in health care spending over the period 1965-2005. This is comparable to an estimate of 15% (regarding the spending increase 1960-2000) advanced by Clemens (2013).

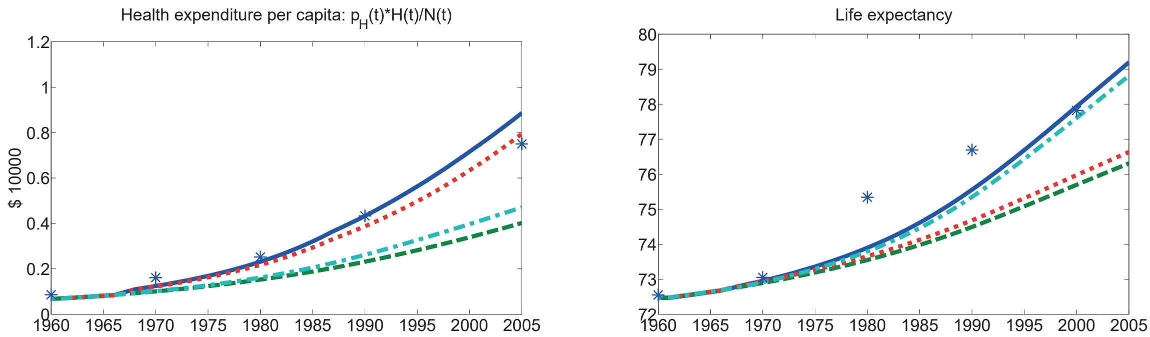

Figure 11: Health expenditure per capita and life expectancy in (i) the benchmark (blue-solid plot); (ii) the main counterfactual without insurance expansion (green dashed plot); (iii) the counter-factual with insurance expansion but without insurance-induced medical change (red dotted plot); (iv) the counter-factual with full medical change but without insurance expansion (cyan dash-dotted plot)

progress, whereas only 0.3 years are due to the introduction of health insurance. The latter result ties in with Skinner and Staiger (2015) who show that when holding the level of medical technology constant, an increase in spending had only modest marginal returns on cardiac mortality, as well as with Finkelstein and McKnight (2008) who find that, 10 years after its introduction, Medicare had no discernible impact on elderly mortality. Indeed, we find that the impact of the health insurance expansion on life-expectancy evolves only (slowly) over time with the benefits from the induced medical change accruing predominantly to later-born cohorts.

4.3 Welfare Analysis

The fact that the expansion of health insurance over the time span 1965-2005 has led to more than a doubling of health care expenditure in 2005 suggests the scope for a substantial welfare loss. This should particularly hold within our stylized model, in which health care expenditures are deterministic, health insurance is merely acting as a subsidy on health care without yielding any offsetting benefit from risk sharing. However, the sizeable impact of insurance expansion on medical progress may offer a form of dynamic return to such subsidies on health care. In order to gauge the welfare consequences of the expansion of health insurance we plot in Figure 12 the lifetime utility of cohorts born over the time span 1900-1980 and examine how it varies across four different scenarios: (i) the benchmark (blue-solid plot); (ii) the main counterfactual without insurance expansion (green dashed plot); (iii) the counter-factual with insurance expansion but without insurance-induced medical change (red dotted plot); and (iv) the counter-factual with full medical change but without insurance expansion (cyan dash-dotted plot). For the purpose of comparison we have normalized to one the lifetime utility of the cohort born in 1900 along the benchmark trajectory.

Naturally, lifetime utility increases with the birth year for all scenarios, as later born cohorts benefit from both productivity growth, translating into higher consumption and health care spending, and medical progress, translating into more effective spending and increasing longevity. A comparison across scenarios reveals the following. Starting from the main counterfactual (with health insurance frozen to the 1965 level, green dashed plot), consider first the direct effect of the introduction of health insurance (red dotted plot). Here, we obtain the expected result that most cohorts experience a reduction in their lifetime utility. This is precisely because of the moral hazard effect of health insurance, triggering excessive health care spending at the expense of consumption. Although this distortion is increasing over time, the associated welfare loss is nevertheless modest even for the latest born cohort. Notably, our calibration suggests that cohorts born between 1900 and 1910 should have benefitted from the expansion of health insurance even when induced medical progress is not accounted for. This is because these cohorts were already retired or close to retirement when Medicare/Medicaid was introduced in 1966. Consequently they enjoyed cheaper access to health care without having to pay the taxes.

Starting again from the main counterfactual (with health insurance frozen to the 1965 level), consider now the isolated impact of the induced medical change (cyan dashed-dotted plot). In spite of the associated (moderate) spending increase, all cohorts benefit from this. Notably, the gains are building up over time, disproportionately benefitting later born cohorts, with the cohort born in 2005 experiencing a 5 percentage point increase in lifetime utility. This relates mostly to cumulating increases in life expectancy afforded by the higher growth rate in the state of medical technology.

The benchmark scenario, embracing both health care expansion and induced medical progress, then balances the two offsetting tendencies from moral hazard and induced medical progress. As it turns out, the benefits from additional medical progress outweigh by a significant amount the utility loss from excessive health care payments for all cohorts. Note that in contrast to the previous counterfactual with induced medical progress for constant 1965 health insurance, the benefit from additional life-years afforded through higher medical progress is now offset by a growing level of excess expenditure from moral hazard. Thus, a priori it is not quite clear whether the welfare gains from greater life expectancy are really worth the increasing moral hazard. However, as is easily seen from Figure 12 the welfare loss from moral hazard is by far not increasing as much over time as the gains from medical technology.

We conclude with the observation that the subsidization of health care expenditure that is implied by health insurance contracts is justified as a means to overcome an intergenerational - and to lesser extent intragenerational - externality associated with the inducement of medical progress: at each point in time, individuals are underinvesting in health care, as they are not taking into account the impact of a higher spending level on medical progress and, thus, on future survival gains.[38] With the direction of the externality, thus, flowing from older to younger (or even yet unborn) generations there is an issue about how the older cohorts can be compensated for stimulating medical progress. Here, the introduction and expansion of Medicare plays an important role: The tax-financed subsidization of health care for the elderly imposes a transfer from younger, working-age generations to the old. While in the absence of induced medical progress such a system would be both inefficient and biased against the young, it provides the appropriate compensation from the young to the old for the inducement of medical progress. Indeed, the health insurance expansion in the US turns out to be a Pareto improvement for the cohorts under consideration. This suggests that tax-financed health care can take on a role similar to unfunded social security that compensates older generations for the cost of educating and, thus, raising the human capital of younger cohorts (Boldrin and Montes 2005; Andersen and Bhattacharya 2017).

[38]Kuhn et al. (2011) show in a related OLG framework that the presence of positive spillovers of health care spending on the survival of others serves as a justification for the subsidisation of health care, coming e.g. in the form of health insurance. In that setting, however, the externality associated with health spending is merely contemporary and does not have a lasting effect.

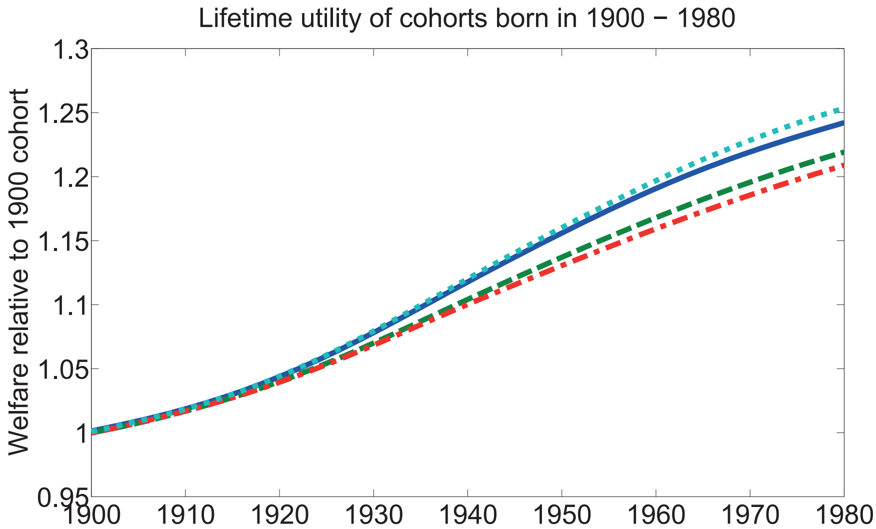

Figure 12: Lifetime welfare for cohorts born from 1900 to 1980 in (i) the benchmark (blue-solid plot); (ii) the main counterfactual without insurance expansion (green dashed plot); (iii) the counter-factual with insurance expansion but without insurance-induced medical change (red dotted plot); (iv) the counter-factual with full medical change but without insurance expansion (cyan dash-dotted plot)

4.4 The Role of Income Growth

The explanation for why the benefits from medical progress increasingly outweigh the loss from moral hazard lies with the ongoing growth of income: As long as per capita consumption is increasing over time, individuals tend to assign an increasing value to life (Hall and Jones 2007). This argument extends to the presence of moral hazard, where individuals are willing to tolerate an increasing distortion from health insurance in exchange for an increase in lifetime, as long as this only slows down but does not reverse consumption growth.[39]

Given this, one may wonder whether health insurance expansion would still yield any gains within a stagnating economy. For this purpose we consider a last counterfactual scenario in which we study the impact of health insurance expansion according to the benchmark under the assumption that productivity stagnates at the 1965 level. Figure 13 contrasts the development of health expenditure per capita, consumption per capita and the average value of life for the benchmark scenario (solid, blue plots) and the counterfactual with productivity stagnation (green, dashed

[39]According to a related application of this argument the growth drag imposed by a large health care system (Kuhn and Prettner 2016) or by an ongoing shift of R&D activity into the medical sector (Jones 2016) is not harmful to welfare as long as there is ongoing GDP/consumption growth.

plots). While health care expenditure continues to increase, albeit at a much reduced rate, due to the expansion of insurance in the counterfactual, this now comes at the expense of stagnating and ultimately declining per capita consumption. The latter trend is mirrored in a stagnation and ultimately decline in the average value of life. As expected, the trade-off between health care and consumption has much more bite in the absence of productivity growth.

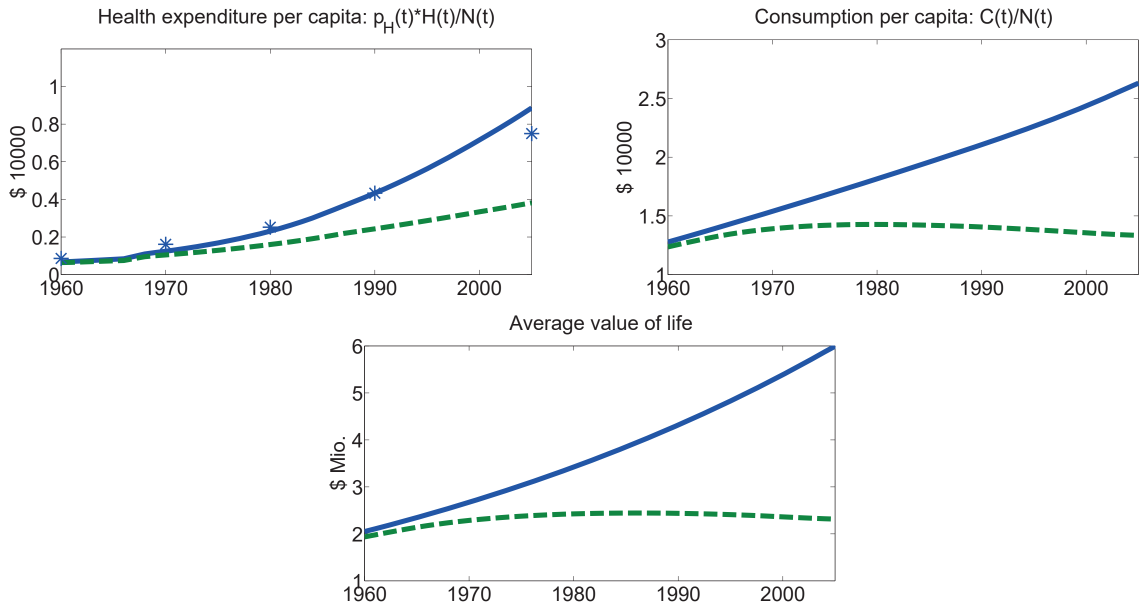

Figure 13: Benchmark (blue, solid) and ”productivity stagnation” counterfactual (green, dashed)

In order to address the question as to whether this leads to a different assessment of the social welfare consequences of the expansion in health insurance, we now consider in Figure 14 a set of equivalent variation exercises in the spirit of Jones and Klenow (2016). Specifically, we consider by what proportion would we need to augment the life-cycle consumption of a representative of a birth cohort living in the main counterfactual scenario without insurance expansion and without induced medical progress, for this representative to attain the level of life cycle utility she would enjoy in a setting in which (i) induced medical progress is realized without an expansion of health insurance (left panel); (ii) there is an expansion of health insurance without induced medical progress, i.e. pure moral hazard (middle panel); and (iii) there is an expansion of health insurance and medical progress is induced, i.e. our benchmark scenario (right panel). For each of these three cases, we calculate the equivalent variation both for a scenario in which productivity grows in line with the benchmark scenario (blue, solid plots) and for a scenario in which productivity stagnates at the

1965 level (green, dashed plots).[40]

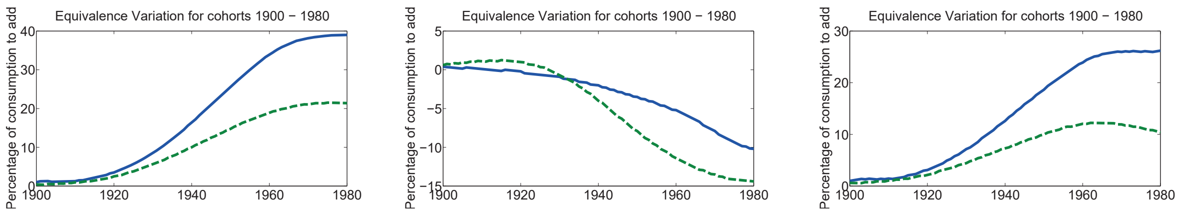

Figure 14: Equivalent variation for induced medical progress only (left), moral hazard only (center) and total insurance effect (right)

Our analysis reveals that irrespective of the presence or absence of productivity growth, members of all cohorts attain a higher life-cycle utility when there is induced medical progress, whereas all cohorts but the earliest born suffer from moral hazard. In the presence of income growth, cohorts born after 1900 would require increasing shares of their respective consumption level to be added for them to attain the same utility as in the presence of medical progress, these shares reaching close to 40% for the 1980 birth cohort in the case in which induced medical progress is realized without an expansion of health insurance (left panel), and to around 25% for the 1980 cohort in the case in which induced medical progress comes with the expansion of health insurance. Conversely, cohorts born after 1910 could be taken away increasing shares of consumption, up to around 10% for the 1980 birth cohort, in order for them to obtain the same utility as under the expansion of health insurance without induced medical progress (middle panel). While this is in line with our earlier findings, the same patterns emerge in the absence of productivity growth with the only difference that medical progress is valued less (with the equivalent variation required to attain the same utility as with induced medical progress and without an expansion of health insurance reaching only a little more than 20% of an (already lower) consumption level for the 1980 birth cohort) and that moral hazard is valued more (the equivalent variation for the 1980 birth cohorts amounting to around 15% of consumption that could be given up). In combination, these differences in valuation imply that the equivalent variation for an expansion of health insurance with induced medical progress declines from a peak level of around 12% for cohorts born around 1965 to 10% for the 1980 birth cohort. While these differences illustrate the quantitative relevance of income growth, the key

[40] We have also calculated the compensating variation, obtaining results which do not differ qualitatively and quantitatively only by a small margin.

finding that even in the absence of income growth all cohorts benefit from the ongoing expansion of health insurance demonstrates the relevance of the dynamic externality. Here, the complementarity between past medical innovations (financed by earlier cohorts) and health insurance is sufficient to trigger an increase in the willingness to pay for longevity-enhancing medical innovation that is large enough to overcompensate the increasing loss from moral hazard associated with the expansion of health insurance. This is true even if for the latest born cohorts, moral hazards leads to a decline in consumption. This notwithstanding, the decline in the equivalent valuation for an expansion of health insurance in the absence of income growth suggests a limit to this mechanism.

5 Conclusion

We have studied the aggregate impact of the health insurance expansion in the US between 1965 and 2005 on health care spending, taking account not only the direct effect through decreases in OOP spending but also the indirect effect through induced medical progress. For this purpose we have constructed a continuous time model of an economy with overlapping generations subject to endogenous mortality and with three sectors: final goods production, health care and medical R&D; and calibrated it to US data covering the time span 1960-2005. Our simulation traces closely the development of most key indicators (such as GDP per capita, the health share, life expectancy, the share of the population 65+, the Medicare share, the growth rate of medical R&D, and the medical R&D share) and explains very well medical price inflation due to the joint impact of productivity growth in the final goods sectors a la Baumol (1967) and medical progress itself.

A first set of results shows that medical progress, insurance expansion and income growth in isolation contribute broadly equally to the increase in health care spending but that more than half of the expenditure increase is explained by the nexus of complementarity between the three drivers. Focusing on the role of health insurance in explaining health care spending growth and medical progress, we find strong effects, with health insurance explaining 60 percent of the 850 percent increase in health care expenditure between 1965 and 2005, and explaining 41 percent increase in the growth rate of medical R&D. Both results are well aligned with empirical evidence. When decomposing the impacts of health insurance on health care spending into a direct moral hazard effect and the impact through medical progress we find moral hazard to explain about 81 percent of the spending increase with the remaining 19 percent falling on medical progress. Looking at the benefits of health insurance in terms of improving health and longevity, we find that while the expansion of health insurance has increased life expectancy by an extra 2.3 years in 2005, only 0.3 years are attributable to the higher health care expenditure associated with moral hazard, whereas 2 years are attributable to induced medical progress. This suggests that while the excessive health care spending due to moral hazard is, indeed, wasteful to a large extent, there are sizeable dynamic benefits to health insurance through the stimulation of medical progress.

A comparison of lifetime utility for cohorts born in the years 1900-1980 shows that while the moral hazard associated with the expansion of health insurance creates modest welfare losses for all but the very early born cohorts, the gains in life expectancy from the induced medical progress more than compensate for this, leading to welfare gains for all cohorts. Indeed, the dynamic development of US health insurance could be viewed as a mechanism to overcome - at least partly - the dynamic externality involved with the stimulation of medical advances toward future gains in life expectancy by way of current health care spending. Strikingly, this holds true even in the absence of productivity-driven income growth as a driver of an increasing willingness to pay for longevity-enhancing innovations.

While our results speak to a dynamic role of health insurance that extends well beyond the benefits from risk sharing, they also suggest that there may be more efficient ways for stimulating medical progress. We leave to future research a more detailed analysis of such policies as well as a more detailed analysis of the distribution of the welfare gains and losses from medical progress and health insurance across the different generations. Given the quantitatively substantial size of the intergenerational externality, the present work raises a set of interesting questions as to the dynamic efficiency of different types of health care finance as well as to the dynamic consequences of health care reforms. We relegate these issues to future research.

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6 Appendix

6.1 Optimal Solution to the Individual Life-Cycle Problem

The individual's life-cycle problem, i.e. the maximization of (1) subject to (2) and (3) can be expressed by the Hamiltonian

$$\mathcal{H} = uS - \lambda_S \mu S + \lambda_k \left(rk + lw - c - \phi p_H h - \tau + \pi + s \right),$$

leading to the first-order conditions

$$\mathcal{H}_c = u_c S - \lambda_k = 0, \tag{26}$$

$$\mathcal{H}_h = -\lambda_S \mu_h S - \lambda_k \phi p_H = 0, \tag{27}$$

and the adjoint equations

$$\dot{\lambda}_S = (\rho + \mu) \lambda_S - u, \tag{28}$$

$$\dot{\lambda}_k = (\rho - r) \lambda_k. \tag{29}$$

Evaluating (26) at two different ages/years (a, t) and $(\widehat{a}, t + \widehat{a} - a)$, equating the terms and rearranging gives us

$$\begin{aligned} \frac{u_c (\widehat{a}, t + \widehat{a} - a)}{u_c (a, t)} &= \frac{\lambda_k (\widehat{a}, t + \widehat{a} - a)}{\lambda_k (a, t)} \frac{S (a, t)}{S (\widehat{a}, t + \widehat{a} - a)} \\ &= \exp \left\{ \int_a^{\widehat{a}} \left[\rho + \mu \left(\widehat{\widehat{a}}, t + \widehat{\widehat{a}} - a \right) - r \left(t + \widehat{\widehat{a}} - a \right) \right] d\widehat{\widehat{a}} \right\}, \end{aligned} \tag{30}$$

which is readily transformed into the Euler equation (20) as given in the main body of the paper.

Inserting (26) into (27) allows to rewrite the first-order condition for health care as

$$-\mu_h (a, t) \frac{\lambda_S (a, t)}{u_c (\cdot)} = \phi (a, t) p_H (t). \tag{31}$$

Integrating (28) we obtain

$$\lambda_S (a, t) = \int_a^{\omega} u (\widehat{a}, t + \widehat{a} - a) \exp \left[- \int_a^{\widehat{a}} (\rho + \mu) d\widehat{\widehat{a}} \right] d\widehat{a}.$$

Using this, we can express the private value of life as

$$\psi (a, t) := \frac{\lambda_S (a, t)}{u_c (a, t)} = \int_a^{\omega} \frac{u_c (\widehat{a}, t + \widehat{a} - a)}{u_c (a, t)} \frac{u (\widehat{a}, t + \widehat{a} - a)}{u_c (\widehat{a}, t + \widehat{a} - a)} \exp \left[- \int_a^{\widehat{a}} (\rho + \mu) d\widehat{\widehat{a}} \right] d\widehat{a}.$$

Substituting from (30) and rearranging we obtain (22) as given in the main body of the paper. Inserting this into (31) and rearranging gives condition (21) in the main body of the paper.

6.2 Equilibrium Relationships with Cobb-Douglas Technologies

Consider the Cobb-Douglas specifications

$$
\begin{aligned}
Y(t) &= A_Y(t)K_Y(t)^{\alpha}\left[L_Y(t)\right]^{1-\alpha} && (32)\\
F(t) &= A_H(t)K_H(t)^{\beta_1}\left[L_H(t)\right]^{\beta_2}, && (33)\\
G(t) &= A_M(t)K_M(t)^{\gamma}\left[L_M(t)\right]^{1-\gamma} && (34)
\end{aligned}
$$

with α, β_1, β_2 and $\gamma \in [0,1]$, and $\beta_1 + \beta_2 < 1$. Period profits are then given by

$$
\begin{aligned}
V_Y(t) &= Y(A_Y(t), K_Y(t), L_Y(t)) - w(t)L_Y(t) - [\delta + r(t)]\, K_Y(t), && (35)\\
V_H(t) &= p_H(t)\, F(A_H(t), K_H(t), L_H(t)) - w(t)L_H(t) - [\delta + r(t)]\, K_H(t), && (36)\\
V_M(t) &= p_M(t)\, G(A_M(t), K_M(t), L_M(t)) - w(t)L_M(t) - [\delta + r(t)]\, K_M(t). && (37)
\end{aligned}
$$

Perfectly competitive firms in the three sectors choose labour and capital so as to maximize their respective period profit (35)-(37). The first-order conditions imply

$$
\begin{aligned}
r(t) + \delta &= Y_{K_Y}(t) = p_H(t)\, F_{K_H}(t) = p_M(t)\, G_{K_M}(t) && (38)\\
w(t) &= Y_{L_Y}(t) = p_H(t)\, F_{L_H}(t) = p_M(t)\, G_{L_M}(t), && (39)
\end{aligned}
$$

i.e. the factor prices are equalized with their respective marginal value products, where the prices for health care, $p_H(t)$, and medical technology, $p_M(t)$, respectively are taken into account.

From the first-order conditions (38) and (39) we then obtain the factor demand functions

$$
\begin{aligned}
K_Y^d(t) &= \frac{\alpha Y(t)}{r(t)+\delta}, && (40)\\
L_Y^d(t) &= \frac{(1-\alpha)\, Y(t)}{w(t)}, && (41)\\
K_H^d(t) &= \frac{\beta_1 p_H(t) F(t)}{r(t)+\delta}, && (42)\\
L_H^d(t) &= \frac{\beta_2 p_H(t)\, F(t)}{w(t)}. && (43)\\
K_M^d(t) &= \frac{\gamma p_M(t) G(t)}{r(t)+\delta}, && (44)\\
L_M^d(t) &= \frac{(1-\gamma) p_M(t)\, G(t)}{w(t)}. && (45)
\end{aligned}
$$

Combining (40) with (41) ,(42) with (43) and (44) with (45) we obtain the equilibrium capital intensity

$$
\begin{aligned}
k_Y^*(t) &:= \frac{K_Y^d(t)}{L_Y^d(t)} = \frac{\alpha}{1-\alpha}\frac{w(t)}{r(t)+\delta}, && (46)\\
k_H^*(t) &:= \frac{K_H^d(t)}{L_H^d(t)} = \frac{\beta}{\beta_2}\frac{w(t)}{r(t)+\delta}. && (47)\\
k_M^*(t) &:= \frac{K_M^d(t)}{L_M^d(t)} = \frac{\gamma}{1-\gamma}\frac{w(t)}{r(t)+\delta}. && (48)
\end{aligned}
$$

and, thus, $K_Y^d(t) = k_Y^*(t)\, L_Y^d(t)$. Using $k_Y^*(t)$ in (32) to rewrite
$Y(t) = L_Y^d(t)\, A_Y(t)\,(k_Y^*(t))^{\alpha}$ and inserting this in (41) we can solve for the equilibrium wage as a function of the interest rate

$$w^*(t) = \widehat{w}(r(t); A_Y(t)) = (1-\alpha)\, A_Y(t)^{\frac{1}{1-\alpha}} \left[\frac{\alpha}{r(t)+\delta}\right]^{\frac{\alpha}{1-\alpha}}.$$

This, in turn, determines the capital intensities $k_Y^*(t) = \widehat{k}_Y(r(t); A_Y(t))$, $k_H^*(t) = \widehat{k}_H(r(t); A_Y(t))$ and $k_M^*(t) = \widehat{k}_M(r(t); A_y(t))$. Using the market clearing condition $F(p_H^*(t); K_H^*(t), L_H^*(t), A_H(t)) = H^d(p_H^*(t); M(t), B(t))$ and (42) and (43) we obtain the general equilibrium price for health care as

$$\begin{aligned} p_H^*(t) &= \widehat{p}_H(r(t), w^*(t); H_d(t), A_H(t)) \\ &= \widehat{p}_H(r(t); H_d(t), A_Y(t), A_H(t), M(t), B(t)) \\ &= \left(\frac{H^d(t)^{1-\beta_1-\beta_2}}{A_H(t)} \frac{(r+\delta)^{\beta_1} w^{\beta_2}}{\beta_1^{\beta_1}\beta_2^{\beta_2}}\right)^{1/(\beta_1+\beta_2)}. \end{aligned}$$

Reinserting this, we obtain the equilibrium utilization of health care, as
$H^d(p_H^*(t); M(t), B(t)) = \widehat{H}(r(t); A(t), M(t), B(t))$. Using the market clearing condition $V_H = p_M G$ and (44) as well as (45) we obtain

$$\begin{aligned} p_M^*(t) &= \widehat{p}_M(r(t), w^*(t)) \\ &= \widehat{p}_M(r(t); A(t), M(t), B(t)) \\ &= \frac{1}{A_M}\frac{(r+\delta)^{\gamma} w^{1-\gamma}}{\gamma^{\gamma}(1-\gamma)^{1-\gamma}}. \end{aligned}$$

Using (43) with $F(t) = H_d^*(t)$ we can determine now $L_H^*(t) = \widehat{L}_H(p_H^*(t), w^*(t), H_d^*(t)) = \widehat{L}_H(r(t); A(t), M(t), B(t))$. Knowing $L_H^*(t)$ we can determine $K_H^*(t)$ from (47), and consequently the value of V_H^* in equation (36). It is now possible to calculate $L_M^*(t)$ based on equation (45) using $V_H = p_M G$. The labour market equilibrium then determines

$$L_Y^*(t) = L(t) - L_H^*(t) - L_M^*(t),$$

where $L(t) = \widehat{L}(r(t); A(t), M(t), B(t))$.[41]

6.3 Solving the Numerical Problem

We pursue the following steps towards tracing out the numerical solution, sketched here for the benchmark scenario, while using the specific functional forms presented in section 3:

1. We derive from the first-order condition for consumption (20) the relationship

$$c(a, t_0+a)^{-\sigma} = c(0, t_0)^{-\sigma} \exp\left\{\int_0^a [\rho - r(t_0+\hat{a}) + \mu(\hat{a})]\, d\hat{a}\right\}. \tag{49}$$

[41]Note that through the impact of the demand for health care on the pattern of survival, labour supply becomes a function of the prices and the states of the economy.

2. We derive the life-cycle budget constraint

$$\int_0^{\omega}\left[\begin{array}{c} w\left(t_0+a\right)l\left(a\right)-c\left(a,t_0+a\right)+\pi(a,t) \\ -\phi(a,t)p_H\left(t_0+a\right)h\left(a,t_0+a\right)-\tau(a,t)+s(t_0+a)\end{array}\right]R\left(a,0\right)da=0,$$

with $R\left(a,0\right)$ as given by (24). We then insert (49) and obtain the consumption level

$$c\left(0,t_0\right)=\frac{\int_0^{\omega}\left[\begin{array}{c} w\left(t_0+a\right)l\left(a\right)+\pi(a,t) \\ -\phi(a,t)p_H\left(t_0+a\right)h\left(a,t_0+a\right)-\tau(a,t)+s(t_0+a)\end{array}\right]R\left(a,0\right)da}{\int_0^{\omega}\exp\left\{\int_0^{a}\left[\frac{1-\sigma}{\sigma}r(t_0+\hat{a})-\frac{\rho+\mu(\hat{a})}{\sigma}\right]d\hat{a}\right\}da} \tag{50}$$

for an individual born at t_0, contingent on the stream of health care, $h\left(a,t_0+a\right)$, and the set of prices $\left\{w\left(t_0+a\right),r(t_0+a),p_H\left(t_0+a\right)\right\}$ over the interval $\left[t_0,t_0+\omega\right]$. Finally, we need to keep track of the constraint on minimum consumption at the level of social security benefits. As is readily checked from the numerical analysis, this constraint is binding only at the highest ages.

3. We derive from the first-order condition for health care (21) a vector of age-specific demand levels

$$h(a,t_0+a)=\left(\frac{\psi(a,t_0+a)\eta(a)(-\kappa)M(t_0+a)}{\phi(a,t_o+a)p_H(t_0+a)}\right)^{\frac{1}{1-M(t_0+a)\kappa(a)}} \tag{51}$$

for all $a\in\left[0,\omega\right]$.

4. We show in section 6.2 that the set of prices $\left\{w\left(t_0+a\right),p_H\left(t_0+a\right)\right\}$ as well as all input and output quantities can be expressed in terms of the interest rate $r(t_0+a)$ alone.

5. Using (49) together with (51) we can calculate the life-cycle allocation for consumption, $c\left(a,t_0+a\right)$, depending on the allocation for health expenditures, $h(a,t_0+a)$, $\forall a\in[0,\omega]$ and on the set of prices $\left\{w\left(t_0+a\right),r(t_0+a),p_H\left(t_0+a\right)\right\}$ over the interval $[t_0,t_0+\omega]$. Vice versa, the allocation of health expenditures can be calculated from the allocation of consumption and the macroeconomic prices.

6. We apply these calculations iteratively on initial guesses of c and h. We then use the results as an initial guess to the age-structured optimal control algorithm, as presented in Veliov (2003). This yields an optimal allocation of individual consumption and health expenditures contingent on an initially assumed $r(t_0+a)$.

7. Drawing on this, we apply the following recursive approximation algorithm: (i) Guess an initial interest rate $r(t_0+a)$ and derive the optimal life-cycle allocation. (ii) Based on this, calculate the market interest rate $r^{*}(t_0+a)$ from the capital market equilibrium $K^{d}\left(r(t_0+a),\widehat{w}\left(r(t_0+a)\right)\right)=K^{s}\left(r(t_0+a)\right)$. (iii) Adjust the initial interest rate, so that it approaches $r^{*}(t_0+a)$, e.g. by setting $r_1(t_0+a):=r_0(t_0+a)+\epsilon(r^{*}(t_0+a)-r_0(t_0+a))$, $\epsilon\in(0,1]$. The process converges to an interest rate for which households optimize and capital demand equals capital supply. The output market clearing condition, $Y(t_0+a)=C(t_0+a)+\dot{K}(t_0+a)+\delta K(t_0+a)$ then determines the dynamics of the capital stock to the next period. (iv) This process is reiterated in a recursive way, employing a solution algorithm based on Newton's method. Equations (49)-(51) allow us to verify ex-post an optimum life-cycle allocation for the focal cohort born at t_0. While the numerical algorithm cannot determine in

a precise way the optimal allocation for other cohorts, it nevertheless structures the allocation in a way that approximates the optimum for all cohorts.

6.4 Details on the Effectiveness of Health Care and Spending Elasticities

In this appendix we provide additional detail on how the effectiveness of health care in lowering mortality is related to the various spending elasticities. For this purpose, let us define the elasticity of mortality with respect to health care spending,

$$\epsilon\left(\mu, h, a, t\right) := \mu_h h/\mu = \kappa(a)M(t) < 0, \tag{52}$$

as "medical effectiveness". Intuitively, medical effectiveness varies with age and increases, in absolute terms, in the state of the medical technology. In our model parametrization, $\kappa(a)M(t)$ ranges from -0.2 to -0.04 in the year 2005 and is thus close to the estimates of Hall and Jones (2007). For the year 1965, for which the level of medical technology is considerably lower, $\kappa(a)M(t)$ ranges from -0.05 to -0.01. This implies a considerable increase in medical effectiveness over the period 1965-2005. While we cannot quote direct evidence on the impact of medical progress on medical effectiveness, Gallet and Doucouliagos (2017) find some evidence in a meta-regression analysis that the elasticity of mortality with respect to health spending in absolute terms does, indeed, increase over time.[42],[43]

In the following, we show how medical effectiveness impacts on the individual demand for health care, and in particular on the relevant spending elasticities and on the complementarity between the insurance, income and medical technology as determinants of demand. It is important to note that in contrast to the macro economic elasticities reported in Subsection 3.2 the relationships derived in the following are given for an individual aged a at time t within a partial equilibrium context (i.e. for a given set of prices and income). From (51) we can calculate the elasticity of health care spending $p_H\left(t\right)h(a,t)$ with respect to the rate of coinsurance $\phi(a,t)$ as[44]

$$\epsilon\left(h, \phi, a, t\right) := \frac{h_\phi \phi(a,t)}{h(a,t)} = -\frac{1}{1-\kappa(a)M(t)} < 0.$$

As $\kappa(a) < 0$, the spending elasticity is negative and smaller than unity in absolute terms. For the year 2000, our simulation yields an average insurance elasticity of -0.86.[45] This is well in line with recent empirical estimates by Kowalski (2015) and relatively close to the estimates in Eichner (1998) and Fonseca et al. (2013) who find a spending elasticity of around -0.6.[46] It also falls into

[42] While the average year of the data underlying the elasticity estimate is insignificant in all regression specifications (where the dependent variable is the spending elasticity), an increase in the age of the data by one year decreases the elasticity estimate by about 0.002. Hence, in 1965 the elasticity should be about 0.002*40 = 0.08 lower in absolute terms than the elasticity in 2005. This is roughly in line with our model parametrization.

[43] The increase of medical effectiveness over time notwithstanding, one may nevertheless consider the spending effectiveness to be relatively low. Here, it should be borne in mind that we are considering the impact of all health care spending on mortality, and, thus, necessarily a very "unfocused" measure of health care. In their analysis of the effectiveness of NHS treatment programmes for cancer and circulatory disease, Martin et al. (2008) report substantially higher elasticities of mortality with respect to condition-specific expenditure.

[44] For a given $p_H\left(t\right)$, we have $\frac{d[p_H(t)h(a,t)]}{dx}\frac{x}{p_H(t)h(a,t)} = h_x\frac{h_x x}{h(a,t)} = \epsilon\left(h, x, a, t\right)$. Thus, the partial equilibrium spending elasticity with respect to x is identical to the elasticity of health care with respect to x.

[45] We calculate the average elasticity by weighting the age-specific elasticities $\epsilon\left(h, \phi, a, t\right)$ with the respective age-shares and summing over all ages.

We apply the same procedure when calculating the average elasticities with respect to income y and with respect to medical technology, M.

[46] As an aside, it is worth noting that our analysis suggests that the spending elasticity is given by $\epsilon = \left(\mu_{hh}h/\mu_h\right)^{-1}$ and, thus, varies inversely with the elasticity of the marginal product of health care in the level of care. Thus,

the interval described by the forward and backward arc elasticities at the macro level (see Table 3).

For the elasticity of health care spending with respect to (individual) income $y\left(a,t\right)$ we obtain

$$\epsilon\left(h,y,a,t\right):=\frac{h_y y\left(a,t\right)}{h(a,t)}=\frac{1}{1-\kappa(a)M(t)}\frac{y\left(a,t\right)}{\psi\left(a,t\right)}\frac{d\psi\left(a,t\right)}{dy\left(a,t\right)}=-\epsilon\left(h,\phi,a,t\right)\times\epsilon\left(\psi,y,a,t\right)>0.$$

The age-specific income elasticity is, thus, given by the product of the spending elasticity in respect to health insurance and the elasticity of the value of life with respect to income. $\epsilon\left(\psi,y,a,t\right)>0$. As there is no proper closed form formulation of this latter elasticity, we conduct a ceteris paribus experiment in which only income grows but, in contrast to the macroeconomic case, all prices, taxes and bequests are kept constant. We obtain here a value of 0.21, which is very close to typical microeconomic estimates (Getzen 2000).

For the elasticity of health care spending with respect to the state of the medical technology $M\left(t\right)$ we obtain

$$\epsilon\left(h,M,a,t\right):=\frac{h_M M\left(a,t\right)}{h(a,t)}=\frac{1-\kappa(a)M(t)\left[1-\ln h(a,t)\right]}{\left[1-\kappa(a)M(t)\right]^2}=-\epsilon\left(h,\phi,a,t\right)\times\frac{1-\kappa(a)M(t)\left[1-\ln h(a,t)\right]}{1-\kappa(a)M(t)}>0.$$

The elasticity is, thus, given by the product of the spending elasticity in respect to health insurance and a scaling term that captures the net impact of medical technology on the marginal productivity of health care. For our calibration we have (i) $h\left(a,t\right)>1$ throughout and (ii) ranges of $M(t)$ and $h(a,t)$ over the time period under consideration for which $1-\kappa(a)M(t)\left[1-\ln h(a,t)\right]\in(0,1)$ is satisfied. Thus, for our representation of the US health care system and economy, medical technology raises the marginal product of health care, implying a positive spending elasticity. This effect tends to diminish with further increases in $M(t)$, as for high levels of medical effectiveness substantial reductions in mortality can be attained even at moderate increases in the consumption of health care.

Indeed, all three elasticities decline in the level of medical effectiveness $\kappa(a)M(t)$, as defined in (52) above. This is certainly intuitive for the case of the insurance elasticity: Individuals are less prone to reduce their health care spending in response to higher coinsurance rates for ages, in which medical care is crucial [implying a high absolute value of $\kappa(a)$], and in settings where medical technology is highly effective [implying a high value of $M(t)$].[47] A similar argument can be made in respect to the income elasticity: if medical care is very effective, individuals will have little incentive to deviate (either way) from the "appropriate" level of health care.

As is readily verified from (51), the complementarity between insurance, income and medical technology (at partial equilibrium level) is governed by the following relationships:

$$\begin{aligned}h_{\phi y}&=\frac{1}{h}\times h_y\times h_\phi=\frac{h}{\phi y}\times\epsilon\left(h,y,a,t\right)\times\epsilon\left(h,\phi,a,t\right)<0,\\h_{jM}&=\frac{\Omega\left(h,M\right)}{h}\times h_M\times h_j=\Omega\left(h,M\right)\frac{h}{jM}\times\epsilon\left(h,M,a,t\right)\times\epsilon\left(h,j,a,t\right);\quad j=y,\phi,\end{aligned}$$

the spending elasticity should be low for those treatments which are particularly effective when precise treatment protocols and/or intensities are observed. To some extent, personalised medicine would be consistent with such a notion of effectiveness.

[47] While we did not find empirical evidence on how spending elasticities depend on age or the state of the medical technology, the finding by Duarte et al. (2012) that the elasticity is typically higher for acute care (e.g. acute appendectomy) rather than elective care (e.g. psychological consultation) is consistent with our model: by definition of "urgency" one would expect acute care to be more effective at the point of treatment.

with $\Omega(h, M) := 1 + \frac{\kappa(a)M(t)[1-\kappa(a)M(t)]}{1-\kappa(a)M(t)[1-\ln h(a,t)]} \in (0,1)$ for our parametrization. It is then readily checked that $h_{\phi M} < 0 < h_{yM}$. Hence, health insurance (as represented inversely by the co-payment ϕ), income and medical technology are all complementary. The complementarity between medical technology and the other two determinants is scaled down by the factor $\Omega(h, M)$.

6.5 Life-cycle

In this appendix, we briefly comment on the individual life-cycle outcomes for a focal cohort, entering at $t = 1950$ aged 20. In Figure 15, the benchmark and counterfactual (without insurance expansion) scenarios are depicted by blue, solid plots and by green, dashed plots, respectively. In both scenarios consumption is hump-shaped: the fact that the interest rate (5.5-7.5% in the benchmark) lies above the rate of time preference (3%) implies rising consumption levels until around age 70. Due to missing annuity markets, consumption falls, however, at higher ages as implied by the first-order condition for consumption (20). Individual health expenditures also follow a hump-shaped pattern. While the demand for health care grows very moderately up to age 40, it then exhibits a strong increase up to age 80 before dropping again for the highest ages.[48] For a more thorough discussion of the underlying life-cycle dynamics we refer the reader to Frankovic et al. (2017).

The impact of the counterfactual absence of an insurance expansion implies a drastic decrease in health care expenditures over the life-course, a consequence of less effective medical technology and higher co-payments. Consumption expenditures increase as individual budgets are less burdened by health care spending. At old age, however, individuals are reducing their consumption levels more rapidly, as the higher mortality risk induces them to discount their late-life utility more heavily as opposed to the benchmark scenario. Indeed, in the absence of the health insurance expansion, life expectancy would have increased from 72.5 years in 1965 to only 75.7 years instead of 78 years in 2000.

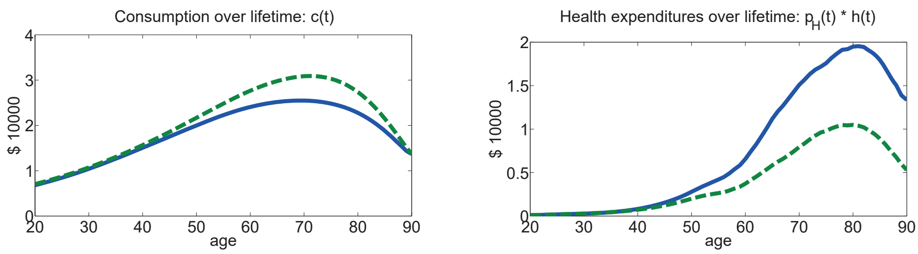

Figure 15: Life-cycle variables in the benchmark (blue, solid) and the counter-factual reflecting constant 1965 insurance level (green, dashed)

[48] The cross-section of age-specific health expenditure for the year 2000 (not shown) matches the data in Meara et. al (2004) until age 80 within a reasonable margin of error. While health care expenditures do not fall in Meara et. al (2004), this is quite possibly due to the open age interval they employ. The averaging of health care expenditures across the highest age groups may well mask an ultimate decline with age as the population shares used for the weighting are rapidly declining, too. Indeed, Martini et al. (2007) identify a hump-shaped pattern when considering a longer range of age-specific expenditure.

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March 2018

ECON WPS

Vienna University of Technology Working Papers
in Economic Theory and Policy

ISSN 2219-8849 (online)
http://www.econ.tuwien.ac.at/wps/

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