Journal of Health Economics 87 (2023) 102717

Contents lists available at ScienceDirect

Journal of Health Economics

journal homepage: www.elsevier.com/locate/jhe

Health insurance, endogenous medical progress, health expenditure growth, and welfare[☆]

Ivan Frankovic[a], Michael Kuhn[b,c,*]

[a] Deutsche Bundesbank, Germany
[b] International Institute for Applied Systems Analysis (IIASA), Austria
[c] Wittgenstein Centre (IIASA, OeAW, University of Vienna), Austria

ARTICLE INFO

JEL classification:
D15
I11
I12
I18
J11
J17
O31
O41

Keywords:
Health care spending
Health insurance
Intergenerational externality
Medical progress
Moral hazard
Overlapping generations

ABSTRACT

We study the impact of health insurance expansion on medical spending, longevity and welfare in an OLG economy in which individuals purchase health care to lower mortality and medical progress is profit-driven. Three sectors are considered: 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 the development of the US economy/health care system from 1965 to 2005 and study numerically the impact of the insurance expansion. 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 subsidization of health care through health insurance creates excessive health care spending, the gains in life expectancy brought about by induced medical progress more than compensate for this.

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 Fig. 1). Since the seminal work by Newhouse (1992), a steady stream of research has emerged that enquires into the causes of this dramatic development (see Chernew and Newhouse, 2011, for a survey). In the course of it, medical progress (Newhouse, 1992, Chandra and Skinner, 2012), income (Hall and Jones, 2007) and social security (Zhao, 2014) have all been identified as potent candidate drivers of medical spending growth.

Interestingly, health insurance has so far been assigned only a minor role in much of the research on the theme. In light of the rapid expansion of health insurance in the US (see Fig. 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). The understatement of health

☆ The views expressed in this paper are those of the authors and do not necessarily represent those of the Deutsche Bundesbank or the Eurosystem. Financial support for this research by the Austrian Science Fund (FWF) under grant P 26184-G11 is gratefully acknowledged. We would like to thank Friedrich Breyer, Ben Heijdra, Mathias Kifmann, Dirk Krueger, Norman Lorenz, Pete Smith, Timo Trimborn, Stefan Wrzaczek, Peter Zweifel as well as, in particular, two anonymous referees for helpful discussions and comments. All remaining errors are ours.

* Corresponding author.
E-mail addresses: ivan.frankovic@bundesbank.de (I. Frankovic), kuhn@iiasa.ac.at (M. Kuhn).

https://doi.org/10.1016/j.jhealeco.2022.102717
Received 1 July 2021; Received in revised form 23 November 2022; Accepted 8 December 2022
Available online 11 January 2023
0167-6296/

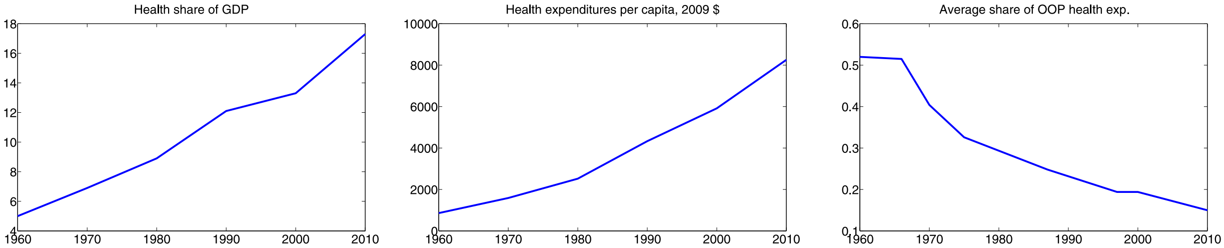

Fig. 1. Health share of GDP, health expenditures per capita in 2009 $ and average share of out-of-pocket expenditures (OOP) in the US from 1960 to 2010. Data sources are discussed in Section 3.1.

insurance may be partly explained as a legacy of the famous RAND health insurance experiment during the late 1970s and early 1980s. Based on the evidence of a rather modest price elasticity of health care spending at the household level insurance could not really explain the spending boom (Manning et al., 1987; Newhouse, 1992). This conclusion has recently been challenged by Fonseca et al. (2021) who estimate a stochastic life-cycle model with endogenous medical spending and find that US spending growth over the time frame 1965–2000 is to a large extent explained by the growth of available income (29 percent) and an increasing generosity in health insurance (37 percent), with medical progress explaining a more modest 9 percent.[1,2] In notable contrast, Fonseca et al. (2021) identify medical progress as the key driver of improvements to longevity.

In addition to the direct impact of health insurance on medical spending, Weisbrod (1991) has conjectured an indirect pathway, namely that the expansion of health insurance coverage created incentives to develop new medical technology. Clemens and Olsen (2021) find empirical support for this hypothesis[3]: 20 to 30 percent of medical equipment and device innovation between 1965 and 1990 is explained by the introduction of Medicare/Medicaid in 1965.[4] 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 macroeconomic 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.

Against the backdrop of these somewhat patchy findings, we study the insurance-spending-innovation nexus in health care within a coherent general equilibrium model of overlapping generations (OLG) who purchase health care, the effectiveness of which is governed by endogenous medical progress. This provides us with a deeper understanding of the mechanisms underlying the empirical findings by Finkelstein (2007), and Clemens and Olsen (2021) and affords new insights about the interaction of income, health insurance and medical progress. Going beyond what is identifiable in the empirical literature, we show that the US health insurance expansion was welfare improving through the stimulation of medical progress, despite sizeable negative welfare effects through moral hazard.

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 should stress early on that, following Finkelstein (2007) and Clemens and Olsen (2021), we focus entirely on the subsidy-character of health insurance. Thus, in a setting in which public health insurance is financed out of taxes and private health insurance out of premia that are fixed at the equilibrium/average level of expenditure, our analysis takes explicit account of the fact that health insurance is generating an incentive for excessive consumption of health care, labelled “ex-post moral hazard” by health economists (e.g. Zweifel and Manning, 2000), a term we will subsequently refer to. With the focus being on the macroeconomic effects of health insurance, we assume representative life-cycles, implying that our analysis does not account for shocks on health such that there is no insurance-related benefit to health insurance. To that end, any of our welfare assessment of health insurance will constitute a lower bound.

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 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.

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 63% of the

[1] Interestingly, research by Feldstein (1971, 1977) pre-dating the RAND experiment had also identified the expansion of health insurance as a major driver of the increase in health care spending.

[2] The findings by Fonseca et al. (2021) are in line with recent estimates of a higher price elasticity of health care spending (e.g. Eichner, 1998; Aron-Dine et al., 2013; Kowalski, 2015).

[3] See also Clemens (2013) for similar findings.

[4] Similarly, Baker (2001) and Baker and Phibbs (2002) find that increasing HMO market shares, implying less generous insurance coverage, were associated with slower diffusion of high-cost magnetic resonance imaging technology and fewer neonatal intensive care units. Acemoglu and Linn (2004), Dubois and de Mouzon (2015) and Finkelstein (2004) find a large impact of (potential) market size on the development of new medical drugs and vaccines, respectively.

expenditure increase until 2005 and 59% until 1990. 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 per capita 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 57% over the time span 1965 to 2005 and by about 39% over the time span 1965 to 1990. The latter compares to a 20%–30% increase in medical equipment and device patenting over the same time span that Clemens and Olsen (2021) estimate as a consequence of the introduction of Medicare/Medicaid. We 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 85% 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 about 1.2 years to the increase in life expectancy between 1965 and 2005. Of this increase, 0.9 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 idiosyncratic shocks to health and 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 1900–1970 reveals that while the moral hazard effect per se is, indeed, generating (modest) welfare losses for most of the birth cohorts, these are overturned 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. One may ask to what extent the positive welfare assessment of the health insurance expansion turns on 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; Chen et al., 2021). Indeed, the benefits from medical innovations are more than offset by the loss from excessive spending incentives in a counterfactual scenario in which GDP stagnates at its 1965 level, suggesting that the welfare benefits of health insurance expansion need to be assessed against the extent of concomitant income growth. At this stage we should recall that health insurance expansion may nevertheless constitute a Pareto improvement when counting in the direct benefits from risk sharing.

Our findings demonstrate 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 other 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 who stand most to gain from health care spend excessively under Medicare insurance and, thereby, impose an externality on tax-paying working-aged individuals. Although the externality related to the excessive consumption of health care turns out to be sizeable, generating a welfare loss of up to -6.5% in consumption equivalent terms for the latest born cohort, within a growing economy the welfare gain from internalizing the benefits from medical progress stand at 7.3% in equivalent variation terms for the latest born cohort. Altogether, the expansion of health insurance is leading to welfare gains to all cohorts and thus consitutes a Pareto improvement.

To our knowledge, the present study constitutes the first comprehensive macroeconomic analysis of the role of health insurance as a stimulus of medical progress. By endogenizing medical progress our work goes beyond earlier approaches examining the impact of exogenous medical progress on health care expenditure and economic performance (Suen, 2009; Fonseca et al., 2021; Frankovic et al., 2020a; Schneider and Winkler, 2021; Kelly and Kuhn, 2022) as well as on the emergence of a longevity gap across income strata (Frankovic and Kuhn, 2019). Other papers dealing with endogenous medical progress are still scarce to date. Jones (2016) considers the optimal mix of medical R&D as opposed to conventional R&D from a social planner perspective but does not consider the general equilibrium of a decentralized economy.[5] Koijen et al. (2016) study the impact of regulatory risks on medical innovation but do this within an infinitely lived representative agent framework, thus, ignoring the important link between medical innovation and longevity. Neither of the studies focuses on the impact of health insurance.[6] Closer in spirit, Böhm et al. (2021) 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 in lowering the accumulation of health deficits as a source of both morbidity and mortality. 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. Due to market-size driven medical R&D, this gap increases over time and, thus, disproportionately benefits younger cohorts. Their work differs from ours in a number of dimensions. Most importantly, they do not consider the private demand for health 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. Finally, Frankovic et al. (2020b) consider the implications of lags in the adoption of medical innovation in the course of the cardiac revolution. The analysis is complementary in as far as the flow of innovations is assumed to be exogenous but its (random) diffusion is endogenous to the size of the health care market. Again, the role of health insurance is not examined.[7]

[5] See Fernandez-Villaverde et al. (2018) for ongoing work on integrating medical progress into a model of endogenous growth within a two-generation OLG setting.

[6] Clemens and Olsen (2021) motivate their 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.

[7] See Kuhn (2022) for a recent survey on the nexus of medical progress, ageing and health care spending.

The macroeconomic impact of US health insurance (reform) features in Jung and Tran (2016, 2022), Conesa et al. (2018), Cole et al. (2019) and Kelly (2020). In all studies but Kelly (2020) survival is exogenous to the utilization of health care, and none of the studies considers medical progress.[8] 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 through the stimulation of medical progress.[9] Cole et al. (2019) identify a case for partial insurance, as under full insurance the welfare loss from long-run reduction in population health due to insufficient preventive investments by health-insured individuals would dominate the short-term benefit from additional risk coverage. Conesa et al. (2018) find that the abolition of Medicare would yield sizeable increases in precautionary savings which boost the capital stock and earnings. While the resulting benefits from higher consumption would outweigh the loss of insurance in a steady-state, even the cumulated welfare gains are lower than the welfare loss along the transition path. In combination with our results, this suggests a strong case for maintaining health insurance. While Conesa et al. (2018) 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. This is conditional, however, on the presence of sustained income growth. Altogether, our findings suggest that the impact of health insurance on medical progress and ultimately health outcomes is an important pathway to consider when assessing the dynamic welfare impact of health insurance.

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 benchmark simulation. 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 an analysis for the case of stagnant productivity. Section 5 concludes. Some proofs and formal elements of the analysis have been relegated to an Appendix that is included with the supplementary material.

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 and Kuhn (2019) and Frankovic et al. (2020a,b) 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 $\mu(a, h(a,t), M(t)) \in (0,\infty)$ satisfies

$$\begin{aligned} \mu_h(\cdot) &< 0,\ \mu_{hh}(\cdot) > 0; \\ \mu_h(a,0,M(t)) &= -\infty,\ \mu_h(a,\infty,M(t)) = 0; \\ \mu_M(\cdot) &< 0,\ \mu_{MM}(\cdot) \geq 0,\ \mu_{hM}(\cdot) < 0 \end{aligned}$$

for all (a,t). Similar to Hall and Jones (2007), we assume that an individual can lower the instantaneous mortality rate by consuming health care, but can only do so with diminishing returns. 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; 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

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

by choosing a stream of consumption and health care on the interval $[0,\omega]$, with ω and $\rho \geq 0$ denoting the maximal attainable age and the rate of time preference, respectively. 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; Abeliansky and Strulik, 2018).[10] Assuming that utility from consumption and utility

[8] Furthermore, none of the models embrace a specific health care sector. As emerges from the analyses in Kuhn and Prettner (2016) and Frankovic et al. (2020a), respectively, the reallocation of production factors across sectors plays a significant role, however, in channelling the economic impact of changes to the health care system.

[9] 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.

[10] It might be argued that health status should show up in the mortality function. The key difference this would make in terms of the mechanics of the model is that through its impact on health status the stream of past health care $h(\hat{a})$ with $\hat{a} \in [0,a)$ would also have an impact on mortality at age a besides the level of current (acute) health care $h(a)$. As pointed out by a reviewer, this may not only reflect preventive health care but also insufficient curative care in the past. The investment aspect of health care tends to strengthen its role for life expansion and welfare. Omitting it for the sake of a leaner analysis as we do, thus, leads to a conservative assessment of the role of medical care in improving life expectancy and welfare.

from good health are multiplicatively separable, one could then generalize (1) to include not only health-dependent duration of life but also health-dependent quality of life. While we refrain from including this within our analysis, we consider this as part of a robustness exercise in Appendix F (see Figure 9).

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

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

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

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 $l(a,t)w(t)$, where $w(t)$ denotes the wage rate per unit of effective labour at time t, and where $l(a,t)$ denotes an individual's effective labour supply depending on age a and time t; (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 Zhao (2014), Conesa et al. (2018), Frankovic and Kuhn (2019) and others by considering a setting without an annuity market. In regard to the boundaries, 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)].

Finally, we note that the only uncertainty individuals face within our model relates to the survival risk. Notably, the mortality process and, thus, the health care spending expended to modify it are deterministic. Thus, health insurance is merely acting as a subsidy in our model, implying a worst case for its assessment.

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,[11] aggregate capital stock, aggregate effective labour supply, aggregate consumption, and the aggregate demand for health care, each at time t:

$$N(t) = \int_0^\omega S(a,t)B(t-a)da, \tag{6}$$

$$K(t) = \int_0^\omega k(a,t)S(a,t)B(t-a)da, \tag{7}$$

$$L(t) = \int_0^\omega l(a,t)S(a,t)B(t-a)da, \tag{8}$$

$$C(t) = \int_0^\omega c(a,t)S(a,t)B(t-a)da, \tag{9}$$

$$H(t) = \int_0^\omega h(a,t)S(a,t)B(t-a)da. \tag{10}$$

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.

[11] 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.

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, 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 trigger 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 cost grows with demand in both private and public hospital markets. They also show that these rigidities are aggravated by technological progress. In light of this evidence our assumption of decreasing returns should be well founded.

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

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

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. Note that we understand medical innovations to be product rather than process innovations. In this sense, improved medical technologies, $M(t)$, raise the effectiveness of health care, $h(a,t)$, in lowering mortality, $\mu_{hM} < 0$; but do not bear on the production function (13) and, thus, on the unit cost of $h(a,t)$. As we show in Frankovic et al. (2020a) this notion of medical progress is consistent with the slow rate of productivity growth of the health care sector (e.g. Faere et al., 1997; Spitalnic et al., 2016) as well as with the inflation of the price for health care. We also show that medical progress leads to a ceteris paribus reduction in the quality-adjusted price for health care, as is again in line with evidence (e.g. Cutler et al., 1998; Dunn, 2012; Lakdawalla et al., 2015; Hult et al., 2018).[12]

Profits in the medical R&D sector are 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. We assume that while the providers of medical technology have market power on the output market (e.g. due to patent protection) they act competitively on the factor markets, which in turn implies $V_M(t) = 0$ in equilibrium.[13] The effectiveness 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 in the health care sector according to

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

This is tantamount to assuming that by setting a price $p_M(t) = V_H(t)/G(.)$ per unit of innovative output R&D firms are able to fully extract competitive rents within the health care sector. We motivate this by referring to (perfect) quality competition between health care providers. The need to provide services based on the state-of-the-art technology to attract demand from patients (or their referring physicians) motivates them to purchase 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.[14]

From the perspective of the R&D industry, our modelling is in the spirit of Acemoglu and Linn (2004) who assume that consumers are willing to pay a mark-up only for the newest generation of technologies, i.e. only for $\dot{M}(t) = G(.)$. Even when assuming patent protection, the entry of new R&D firms will then lead to the erosion of the future profit stream beyond t. While this abstracts from a number of features of patenting and the R&D processes at the firm level, we note that it is consistent with the industry-level modelling and evidence in e.g. Acemoglu and Linn (2004) or Kyle and McGahan (2012).[15]

[12] An increase in total factor productivity in the health care sector, A_H, is much more difficult to reconcile with the evidence. First, it contradicts the finding of slow productivity growth in respect to non-quality-adjusted clinical output in Faere et al. (1997) and Spitalnic et al. (2016). Second, as can be glanced from equation (C.12) in Appendix C, an increase in total factor productivity would imply a decline in the nominal price for health care, p_H, which stands in contrast to observed medical price inflation. Of course, one could reinterpret medical output $h(a,t)$ as "effective", i.e. quality-adjusted, units of health care and, thus, p_H as a quality-adjusted price. However, this introduces an unnecessary level of abstraction into the model and renders much more difficult its calibration in respect to the observed nominal price p_H and expenditure $p_H H(t)$.

[13] This twin assumptions of market power in the product market and perfect competition in the factor markets are typical for the modelling of R&D in macroeconomic contexts (e.g. Romer, 1990; Kuhn and Prettner, 2016).

[14] Of course, the notion of perfect competition within the health care sector amounts to a stylization. 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 complicated model of imperfect competition should give rise to any different patterns of the relevant data.

[15] Specifically, our model features a positive impact on R&D of market size and a negative impact of the interest rate. A positive impact of patent protection can be addressed as part of the generalization presented in Appendix B.

The formulation of medical R&D as a process that is (primarily) fuelled by the demand for innovations by the domestic (US) health care sector may be criticized on a number of counts: it abstracts from (i) public R&D that often lays the basis for private R&D; (ii) patent protection; (iii) international demand for medical innovations; and (iv) the subsidization of private medical R&D (e.g. through NIH programmes in the US). In Appendix B we sketch a generalization of the model that allows to capture the four channels (if in a stylized way). We show the following. (i) Public R&D can be understood to directly enter a generalized measure of total factor productivity $A_M(t)$. (ii) Patent protection can be understood as a measure $x(t) \in [0,1]$ of the extent to which R&D firms can extract surplus $V_H(t)$ from the health care sector. (iii) and (iv) Profits generated from international sales $\overline{V}_M(t)$ and the subsidization of private R&D at rate $s \in [0,1]$ can be incorporated as a mark-up onto the domestic price for innovations. Perfect competition in the factor markets can then be shown to erode the mark-up and lead to an equilibrium price $p_M(t)^*$ that is equivalent to the one in our baseline model, while subsidies, the extent of patent protection and international demand translate into an expansion of R&D output, $\dot{M}(t) = \frac{x(t)V_H(t)+\overline{V}_M(t)}{(1-s)p^*_M(t)}$. Notably we see that despite these amendments R&D output increases proportionately with the value of the home market $V_H(t)$, implying that changes to this value (under an expansion of health insurance) will scale into higher R&D. In light of consistent evidence of a US world market share in excess of 50% for pharmaceuticals and medical technology,[16] this suggests a sizeable impact on R&D of variations in $V_H(t)$ whatever is the level of $\overline{V}_M(t)$. Our calibration in Section 3.1 matches the growth rate of R&D output $\ddot{M}(t) := d\dot{M}(t)/dt$ against the rate of US patent growth and the time path of health expenditure in the data by selecting an appropriate level and growth trend on total factor productivity $A_M(t)$. Given that the exogenous drivers of R&D in (i)-(iv) are reflected in the rate of US patent growth, they can be understood to be embedded in the calibration of $A_M(t)$ as a generalized notion of total factor productivity. Notably, the exogenous trend in $A_M(t)$ remains present in the counterfactual simulations undertaken in Section 4.1, such that the results reflect home market impacts on R&D. Our analysis shows that the expansion of US health insurance explains about 39% of the rate of medical innovation over the time span 1965 to 1990, which is comparable in magnitude to the findings by Clemens and Olsen (2021) who estimate that 20% to 30% of medical patenting over the same time horizon is explained by the introduction of Medicare/Medicaid in 1965. Clemens and Olsen (2021) further show that while the medical patent share in the US was following a similar time path to the rest of the world before the introduction of Medicare/Medicaid, it showed a deviating upward trend afterwards. The absence of a sizeable boost to innovation rates abroad is consistent with a home market bias.[17]

2.4. Health insurance, social security and accidental bequests

Health expenditures are subsidized through (a) private health insurance with coinsurance rate $\phi_P(a,t)$, and (b) public insurance provided by Medicare, Medicaid and other public programmes. We assume that Medicare is only available to the elderly (after the mandatory retirement age $a_R = 65$) with coinsurance rate $\phi_{MC}(a,t) > 0 \Leftrightarrow a \geq a_R$ and Medicaid only to those of working age ($a < a_R$) with a coinsurance rate $\phi_{MA}(a,t) > 0 \Leftrightarrow a < a_R$. The remaining public programmes are assumed to be available to all age-groups at a coinsurance rate $\phi_{RP}(a,t) > 0$. Altogether, coinsurance at (a,t) is then given by

$$\phi(a,t) = \phi_P(a,t) + \phi_{MC}(a,t) + \phi_{MA}(a,t) + \phi_{RP}(a,t).$$

Private health insurance is financed through a "risk-adequate" premium equal to the expected health expenditure that is covered by the insurance. The premium is thus given by

$$\tau_P(a,t) = \left[1 - \phi_P(a,t)\right] p_H(t) h^*(a,t), \tag{18}$$

where $h^*(a,t)$ denotes the equilibrium consumption of health care at age a and time t. All public programmes are financed through payroll taxes with the rates $\hat{\tau}_{MC}(t)$, $\hat{\tau}_{MA}(t)$ and $\hat{\tau}_{RP}(t)$, such that the budget constraints

$$\int_{a_R}^{\omega} \left[1 - \phi_{MC}(a,t)\right] p_H(t)\, h^*(a,t) N(a,t) da = \hat{\tau}_{MC}(t) w(t) L(t), \tag{19}$$

$$\int_{0}^{a_R} \left[1 - \phi_{MA}(a,t)\right] p_H(t)\, h^*(a,t) N(a,t) da = \hat{\tau}_{MA}(t) w(t) L(t), \tag{20}$$

$$\int_{0}^{\omega} \left[1 - \phi_{RP}(a,t)\right] p_H(t)\, h^*(a,t) N(a,t) da = \hat{\tau}_{RP}(t) w(t) L(t) \tag{21}$$

hold.

In our numerical analysis we assume $\pi(a,t)$ to be pension benefits, implying that

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

[16] While publicly available sales data is scarce, Scott Morton and Kyle (2012) refer to a 50% percent share of the US in world pharmaceutical sales since at least the 1980s. The US market share for newly developed pharmaceuticals stood at even 63.7% over the time span 2015–2020 according to the European Federation of Pharmaceutical Industries and Associations "The pharmaceutical industry in figures: Key data report 2021".

[17] Thomas (1996) reports that in 1985, US-based pharmaceutical companies were selling a little less than 60 percent domestically, which further corroborates the claim of a sizeable home market effect.

with $\pi(t)$ a uniform pension benefit at time t and a_R the retirement age. In such a setting the individual supply of effective labour follows $l(a,t) = \hat{l}(a,t) \geq 0 \Leftrightarrow a < a_R$ and $l(a,t) \equiv 0 \Leftrightarrow a \geq a_R$. Social security is financed through a payroll tax with the rate $\hat{\tau}_{\Pi}(t)$ such that the social security budget constraint

$$\int_{a_R}^{\omega} \hat{\pi}(t) N(a,t) da = \hat{\tau}_{\Pi}(t) w(t) L(t) \tag{22}$$

is satisfied.

Overall, we obtain the following tax payments from the perspective of an (a,t)-individual

$$\tau(a,t) = \left[\hat{\tau}_{MC}(t) + \hat{\tau}_{MA}(t) + \hat{\tau}_{RP}(t) + \hat{\tau}_{\Pi}(t)\right] w(t) l(a,t) + \tau_P(a,t).$$

Note that the public health insurance taxes as well as the social security tax tend to redistribute surplus across age groups and are non-distortionary since labour supply is not a decision variable. Detail on the specific calibration of health insurance and social insurance is provided in Section 3.1.

Finally, we assume that per capita bequests are given by

$$s(t) = \frac{\int_0^{\omega} \mu(a,t) k(a,t) N(a,t) da}{N(t)},$$

following an equal sharing rule.[18]

2.5. Individual life-cycle optimum

In Appendix A we show that the solution to the individual life-cycle problem is given by the following two sets of conditions (see Appendix A for the corresponding dynamics)

$$\frac{u_c(c(a,t))}{\exp\left\{-\int_a^{\hat{a}} \left[\rho + \mu\left(\hat{\hat{a}}, t + \hat{\hat{a}} - a\right)\right] d\hat{\hat{a}}\right\} u_c\left(c\left(\hat{a}, t + \hat{a} - a\right)\right)} = \exp\left[\int_a^{\hat{a}} r\left(t + \hat{\hat{a}} - a\right) d\hat{\hat{a}}\right], \tag{23}$$

$$\psi(a,t) = \frac{-\phi(a,t) p_H(t)}{\mu_h(a,t)} \quad \forall (a,t), \tag{24}$$

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 (23) requires that the marginal rate of intertemporal substitution between consumption at any two ages/years (a,t) and $\left(\hat{a}, t + \hat{a} - a\right)$ 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).

Condition (24) 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, $\left[\mu_h(a,t)\right]^{-1}$. The private value of life is defined by

$$\psi(a,t) := \int_a^{\omega} v\left(\hat{a}, t + \hat{a} - a\right) R\left(\hat{a}, a\right) d\hat{a}, \tag{25}$$

with

$$v(a,t) := \frac{u(c(a,t))}{u_c(\cdot)}, \tag{26}$$

and

$$R\left(\hat{a}, a\right) := \exp\left[-\int_a^{\hat{a}} r\left(t + \hat{\hat{a}} - a\right) d\hat{\hat{a}}\right], \tag{27}$$

and amounts to the discounted stream of consumer surplus, $v = u(\cdot)/u_c(\cdot)$ taken over the expected remaining life-course $[a,\omega]$. 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, $\mu_M\left(\hat{a}, t + \hat{a} - a\right) < 0$, cause a reallocation of consumption towards later life-years over the remaining life-course $\hat{a} \in (a,\omega)$. 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 health insurance coverage, and with the state of the medical technology. Our numerical analysis shows that these same three drivers of the (individual and aggregate) demand for health care are operative in general equilibrium.

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

In order to discuss the demand function for health care, we have provided a representation of the first-order conditions for each age/time pair (a,t). We provide and discuss the associated life-cycle dynamics for $c(a,t)$, $h(a,t)$ and $\psi(a,t)$ in Appendix A

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 $\{r(t), w(t), p_H(t), p_M(t)\}$.[19] 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 (23) and (24) 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 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 C 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 development of longevity, the institutional changes as well as the life-cycle profiles (see Section 3.2 and Appendix E). We subsequently use this to examine the role of health insurance in a number of counterfactual numerical experiments. While we assume general equilibrium, we do not impose balanced growth assumptions but rather consider the economy's development over the time span 1960–2005 as a transition path between two steady states, lying outside the time frame under consideration. Technical information on the numerical solution method is provided in Appendix D.

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.[20] In our model, a "birth" at age 20 implies a maximum age $\omega = 80$. Population dynamics are partly endogenous due to mortality that is determined within the model and partly exogenous due to a fixed growth schedule of "births" at rates $\nu(t)$. 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 endogenous mortality) to match the age-structure of the United States between 1965 and 2005, see Table 2.[21] 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 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.

19 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 $K_M(t) = K(t) - K_Y(t) - K_H(t) \in (0, K(t))$.

20 We follow the bulk of the literature and neglect life-cycle decisions during childhood.

21 Note that our 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.

Mortality

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

$$\mu(a,t) = \eta(a,t)h(a,t)^{\kappa(a)M(t)}, \tag{28}$$

where $\eta(a,t)$. is an exogenous shifter of mortality. We then calibrate the parametric components of (28) as follows.

First, we guess values for $h(a,t), \kappa(a)$ and $M(t)$.[22] In order to capture the age-component of $\eta(a,t)$, we consider the year 1965 and find the pattern for $\eta(a, 1965)$ that generates age-specific mortality rates for the US that match the data in the Human Mortality Database given the guesses for other components of the equation.[23] Imposing empirically observed time-paths for age-specific mortality, we then fit a time trend to $\eta(a,t)$ that explains 50% of the decline in average mortality over the time span 1960–2015, leaving the other 50% explained to health care. In doing so, we follow the evidence in Ford et al. (2006), Cutler (2008), Buxbaum et al. (2020) and Fonseca et al. (2021) that around 50% of the decline in mortality can be attributed to medical care.[24,25] In order to gauge the robustness of this assertion, we consider in Appendix F (Figure 5) both a downward and upward deviation of $\eta(a,t)$ by a factor of 0.5 and 1.5, respectively.[26] Considering the impact of these changes on health care spending, life expectancy and the rate of medical progress within the benchmark and counterfactual scenario, respectively, we find that besides the expected shift in the level of life expectancy, our results are largely robust.

Second, and turning to the part of mortality that is amenable to health care, we now reset κ, such that the elasticity of mortality with respect to health care utilization, $\kappa(a)M(t)$, lies in the range of values provided by Hall and Jones (2007).[27]

Third, we choose the value for the total factor productivity in the medical R&D sector A_M, as well as the initial level and growth rate of $M(t)$, such that the growth rate of medical patents ($\ddot{M}$) is in line with empirical data (see Subsubsection **Production** below). This implies deviating from the initially guessed path for $M(t)$. The new $\kappa(a)$ and $M(t)$ are now used as initial guesses, and the procedure is repeated until we obtain a set of mutually consistent parameters, which also implies the paths for mortality and health expenditures observed in the data.

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 $\sigma = 1.1$ which is within the range of the empirically consistent values suggested by Chetty (2006). Setting $b = 15$ then guarantees that $u(a,t) \geq 0$ throughout and generates an average value of life across the population at time $t = 1965$ and $t = 2000$ that lies within the range of plausible estimates, as suggested by Costa and Kahn (2004), Murphy and Topel (2006) and Hall and Jones (2007) and documented in Table 2. Moreover, we assume a standard 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.[28] Given that retirees cannot usually borrow 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.

[22] We choose the initial guess for $h(a,t)$ to be in line with trends in age-specific health expenditures as well as the total aggregate share of health-expenditures in the US economy over time as reported by the National Health Expenditure Tables in the National Health Accounts (NHA).

[23] The database is available at https://www.mortality.org/. See also Frankovic et al. (2020b) for a visualization of the mortality data.

[24] Ford et al. (2006) decompose the 1980–2000 decline in coronary mortality in the US into contributing factors and show that around 47% can be explained by medical treatments. Cutler (2008) arrives at a figure of 55% for cancer and Buxbaum et al. (2020) confirm this in respect to a contribution of 48% of pharmaceuticals and medical care to the 1990–2015 increase in life expectancy. Finally, Fonseca et al. (2021) arrive by way of structural estimation at a contribution of medical progress of 47% to the increase in US life expectancy between 1965 and 2005

[25] While it is straightforward to interpret the 50% of the decline in mortality that is explained by the time trend of $\eta(a,t)$ as the overall outcome of behavioural, social (educational expansion) and environmental changes, we were unable to retrieve evidence that would disentangle these effects, which may reinforce or offset each other (e.g. a decline in smoking being offset by an increase in obesity). While this would be an interesting exercise in its own right, it is immaterial for the present analysis. Furthermore, one may question whether the impact of behaviours as well as social and environmental circumstances on mortality interacts in a multiplicative way with the impact of health care. While lacking robust evidence on such a complementarity, we believe it to be intuitive. Provided we are considering life-saving types of medical care, such care is most effective for unhealthy individuals who are facing a high mortality risk due to behavioural, social or environmental factors.

[26] While this shifts the level of mortality, importantly, it also alters the exogenous time trend to half and 1.5 times the benchmark trend, respectively.

[27] Specifically, $\kappa(a)M(t)$ 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.

[28] 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.

Effective labour supply and income

We assume effective labour supply $l(a,t) = l_1(a)\, l_2(t)$ to be composed of a component $l_1(a)$, reflecting age-specific labour supply, and a time-specific component $l_2(t)$, reflecting the impact of general health status on earnings as recently identified by Kotschy (2021). We comment on these two components in turn.

Following Frankovic et al. (2020a,b), we construct the age-specific labour supply $l_1(a)$ by employing an age-specific income schedule built from 2003 earnings data [Bureau of Labour Statistics (BLS), Current Population Survey (CPS)] and rescaling it 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 labour 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.

Following recent evidence by Kotschy (2021), we assume that the health improvements that underlie the ongoing increase in longevity come with general productivity gains, as captured by $l_2(t)$. Considering quasi-experimental variation in cardiovascular mortality across US states over the time span 1940–2000, Kotschy (2021) identifies a causal impact of mortality, or equivalently, life expectancy on productivity, which – importantly – is to large extent not transmitted through changes in individual labour supply but rather through changes in hourly wages $l_2(t)\, w(t)$. The wage increase can partly be attributed to educational investments triggered by longevity improvements and partly to a direct effect of better cardiac treatment on productivity. Either way, we assume that at the point at which they decide on their health care, individuals take the hourly wage rate as given. Following the evidence in Kotschy (2021) we thus assume

$$l_2(t) = \left(\frac{LE(t)}{\overline{LE}}\right)^{\chi},$$

where $LE(t)$ is life-expectancy at birth at time t, and where $\overline{LE} > 0$ and $\chi > 0$. Following Kotschy's (2021) estimates, we set $\chi = 1.65$ and then choose $\overline{LE} = 78$ for the purpose of normalization.[29]

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 1.33% per year, such that the GDP per capita is growing in line with the data.[30] We set the elasticity of capital and labour in the production of health care (13) to $\beta_1 = 0.1945$ and $\beta_2 = 0.778$, respectively,[31] 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 time span 1960–2005, see Table 2.[32] Total factor productivity in the medical sector, $A_H(t)$, is assumed to grow at a rate of 0.5%, reflecting slow productivity growth within labour-intensive sectors.[33] For the production of medical R&D according to (15) we assume $\gamma = 0.33$, 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 $A_M = 0.09$ is chosen such that (i) the resulting path of R&D output, $\dot{M}(t)$, is consistent with the observed patterns of health expenditure $h(a,t)$ and mortality $\mu(a,t)$ over time (see Subsubsection **Mortality**); and (ii) 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 $\delta = 0.05$.

Health insurance and social security

In order to calibrate the coinsurance rate for the various forms of health insurance – private, Medicare, Medicaid and other public (for details recall Section 2.4) – we set the retirement age $a_R = 65$ and employ data on coverage in the US 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 (≥65 years), providing information on the proportions of total health expenditures that were paid for out-of-pocket and through private insurance, Medicare, Medicaid and other public insurance programmes, respectively.[34] Fig. 2 shows the evolution

[29] Recalling that $w(t)$ and $L(t) = \int_0^{\omega} l(a,t) S(a,t) B(t-a) da$ denote the wage rate per effective unit of labour and effective labour supply, respectively, we can then write the hourly wage as $l_2(t)\, w(t)$ and effective labour supply as $L(t) = l_2(t) \int_0^{\omega} l_1(a) S(a,t) B(t-a) da$, where $l_2(t)$ is a measure of health-related productivity and where $\int_0^{\omega} l_1(a) S(a,t) B(t-a) da$ is the aggregate supply of man hours.

[30] 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.

[31] We start from the estimates of $\beta_1 = 0.2$ and $\beta_2 = 0.8$ in Acemoglu and Guerrieri (2008) but then reduce both values to match the medical R&D share in the US while preserving that $\beta_2 = 4\beta_1$.

[32] We construct the empirical targets for the medical R&D share of GDP from Table 2 in the following way. We use the time series on US R&D expenditures from the Federal Reserve Bank of St. Louis (Table "Y694RC1A027NBEA") and use GDP data from the same database (Table "GDPA") to construct R&D shares of GDP for each year. We then use data from Figure 2 in Jones (2016), which state the share of US R&D expenditures devoted to medical themes. (We use the mean across the multiple data sources employed by Jones (2016).) Combining this data we obtain a time series for the medical R&D-share of GDP in the US.

[33] 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 $A_H(t)$.

[34] 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 programmes 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 Medicare only by the elderly we can construct the time-series in Fig. 2. All NCHS "Health" reports are available at https://www.cdc.gov/nchs/hus/previous.htm.

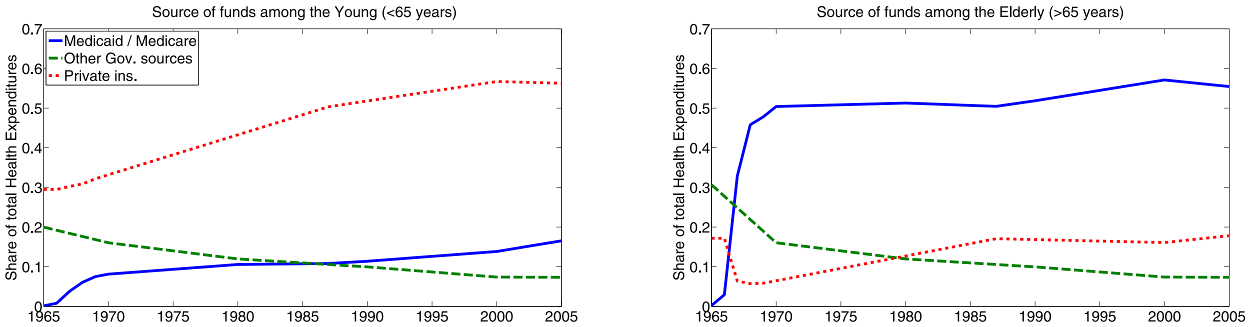

Fig. 2. Share of total health expenditures over time covered by Medicaid (for the young) and Medicare (for the elderly), by other government programmes, and by private insurance for the young (left) and for the elderly (right).

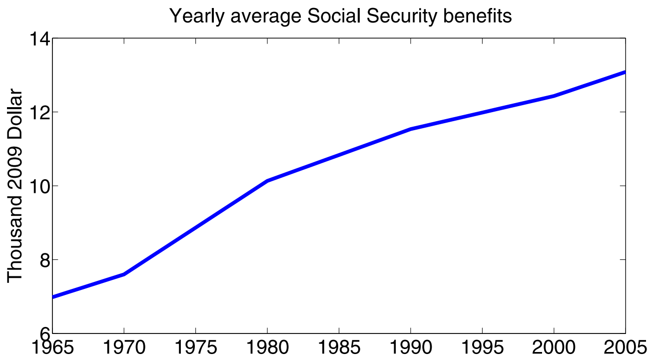

Fig. 3. Yearly average Social Security benefits from 1965 to 2005 in 2009 US Dollars.

Table 1
Model parameters.

Parameter & Functional forms	Description
$\omega = 80$	Life span
$t_0 = 1950$	Entry time of focal cohort
$\rho = 0.03$	Pure rate of time preference
$\sigma = 1.1$	Inverse elasticity of intertemporal substitution
$b = 15$	Constant utility of being alive
$a_R = 65$	Mandatory retirement age
$\delta = 0.05$	Rate of depreciation
$\alpha = 0.33$	Elasticity of capital in Y
$\beta_1 = 0.1945$	Elasticity of capital in F
$\beta_2 = 0.778$	Elasticity of labour in F
$\gamma = 0.33$	Elasticity of capital in G

of insurance coverage from 1965 to 2005 for the young and for 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.

Private health insurance premia, $\tau_P(a,t)$, are then determined through the actuarial constraint (18), and the tax rates, $\hat{\tau}_{MC}(t)$, $\hat{\tau}_{MA}(t)$ and $\hat{\tau}_{RP}(t)$, for the various public programmes through the respective budget Eqs. (19)–(21).

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 Fig. 3).

Finally, the social security tax rate $\hat{\tau}_{\Pi}(t)$ is determined through the budget constraint (22).

Overview of parameters and targets

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.

Table 2
Targets to match.

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: 72.9 (1965), 77.9 (2000) Data : 72.6 (1965), 77.9 (2000)
$\nu(t)$	Share of elderly	Model: 15.3% (1965), 18.4% (2000) Data : 14.8% (1965), 17.3% (2000)
σ	Income elasticity of health care spending	Income elas. of 0.19 (micro) and 1.05 (macro)
b	Value of life	Model: 1.5 Mio. (1965), 3.7 Mio. (2000) Data: 1.1-2.1 Mio (1960), 4.1-5.3 Mio (1980) Costa and Kahn (2004)
$l_1(a)$	Income schedule employment-population ratio	Perfect match by construction 2003: Model: 63%, Data: 62%
$A_Y(t)$	GDP per capita	See Fig. 4
A_M	Growth rate of $\dot{M}(t)$	Model: 4.1%, Data: 4.2%
β_2	Medical R&D share of GDP	Model: 0.14% (1965), 0.41% (2000) Data : 0.14% (1960), 0.42% (2000)
$\phi(a,t)$	Avg. out-of-pocket expenditure share Medicare share of GDP	See Fig. 5 See Fig. 5

Based on our benchmark simulation (see Section 3.2), we obtain an arc elasticity of 1.02 for health insurance and 1.05 for income.[35] The value we find for the insurance elasticity is reasonably well in line with recent evidence by Eichner (1998), Kowalski (2015) and Fonseca et al. (2021). The value we obtain for the income elasticity lies within the range of estimates based on macroeconomic data, as reported by Acemoglu et al. (2013).

Finally, we perform an extensive set of robustness analyses in Appendix F with respect to the following parameters: The levels of total factor productivity in the three sectors, A_M, A_Y and A_H, respectively; the mortality shifter, η; the production elasticities in the health care sector, β_1, β_2; the capital elasticity in the R&D sector, γ; the elasticity of labour supply with respect to life expectancy at age 60, ξ; the direct benefits from health in the utility function, as proxied by the elasticity on survival, $1+\theta$; the inverse of the elasticity of intertemporal substitution, σ; and the rate of time preference, ρ.

For the robustness analysis we run both the benchmark scenario as well as the main counterfactual, in which co-insurance rates are held fixed at their level of 1964, with alternative parametrizations. Specifically, we change the values of selected parameters (one at a time), while keeping everything else in line with the baseline calibration. In general, we conduct simulations with the tested parameter set to either a lower value (generally reduced by 50% relative to its baseline value) or a higher value (generally raised by 50%). We present results in respect to three key outcomes: (a) health expenditure per capita, (b) life-expectancy and (c) medical technology. Additionally, we calculate selected metrics on the role of the insurance expansion in explaining outcomes. Overall, we find that the share of insurance expansion in explaining the change in the three outcomes is broadly robust to the changes in parametrizations that were undertaken. The only variable proving to be critical is the inverse of the elasticity of intertemporal substitution σ. Here, larger values imply strongly diminishing returns to consumption and thus a stronger incentive for individuals to transfer utility into the future by way of increasing survival. This triggers a strong boost in longevity, health care spending and consequently medical progress. The extent to which insurance expansion explains outcomes diminishes considerably in this case, with productivity growth taking on more importance. Such a lack of robustness is well known from the literature (e.g. Hall and Jones, 2007; Schneider and Winkler, 2021), but we note that with $\sigma = 1.1$ we select a value for the inverse of the elasticity of intertemporal substitution that is consistent with empirical evidence and, indeed, close to the preferred value of 1, as identified by Chetty (2006).

3.2. Benchmark

In this section, we 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. Detail on the individual life-cycle outcomes is contained in Appendix E.

[35] 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 $\frac{(p_H H)_{2005} - (p_H H)_{1965}}{((p_H H)_{2005} + (p_H H)_{1965})/2}$ and $\frac{x_{2005} - x_{1965}}{(x_{2005} + x_{1965})/2}$ denoting the percentage change in $p_H H$ and $x = \{\phi :$ average co-insurance, $y :$ income$\}$, respectively, averaged over the time period 1965–2005.

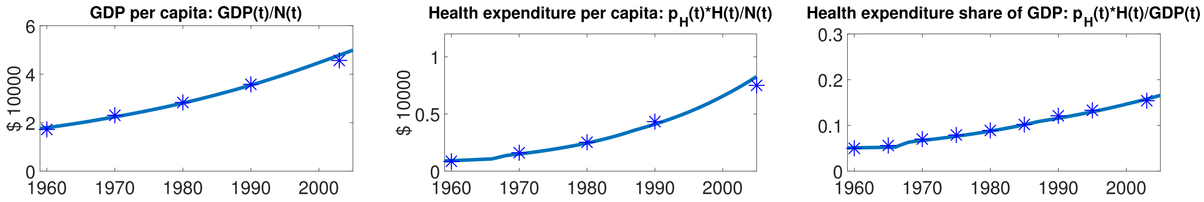

Fig. 4. GDP and health expenditures per capita as well as the GDP share in the benchmark scenario (blue, solid line) and data (asterisks).

Fig. 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 2.5 and health expenditures by a factor of 7.9 over the time span 1960–2005.[36] The two developments imply an about three-fold increase of the health expenditure share of GDP over the 40 years under consideration.

While the increase in GDP is predominantly driven by the exogenous growth of total factor 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.[37]

Fig. 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 an annual growth of $\dot{M}$ at 4.2%, identical to the growth rate of patents at 4.2% per year found in the data.[38] Note, that we do not directly target the development of health expenditures over time. 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. Fig. 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. Given we are not targeting them in our calibration, the exogenous coinsurance rates result in a good match in the simulation.[39]

The market interest rate, $r(t)$, is endogenously determined within the model, and falls over the time period under consideration (see Fig. 6). 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., 2007; De Nardi et al., 2010; Aksoy et al., 2019).

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. (2020a). 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.[40]

Wage growth reflects the increase in productivity and the increasing relative scarcity of labour as described above. As the health care sector is comparatively labour-intensive, the wage increase overcompensates the drop in the interest rate and induces a growth of the price of health care over time. We can compare p_H with the ratio of the medical 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 1.3-times faster than the overall CPI according to BEA. This compares quite well with the 1.29-fold increase in p_H over the same time span in the benchmark economy. While there may be 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.

[36] We overestimate health expenditure growth during 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.

[37] While the analysis presented here traces the full dynamics over the transition path, we have also decomposed the increase of health care expenditure per capita between 1965 and 2005 according to its drivers. We find that 6.0% of the spending increase are explained by medical progress (understood as an exogenous increase in M in this exercise), whereas 18.3% and 18.7% are explained by insurance expansion and income growth, respectively. This compares against the 8.5%, 37% and 28.8% that Fonseca et al. (2021) attribute to medical progress, insurance expansion and income growth in a similar exercise. The difference, in particular, in respect to the impact of insurance and income relates to much stronger complementarity between the three drivers in our framework, 59.4% as opposed to 25.7% in Fonseca et al. (2021). In turn, this is fully consistent with the different conceptualization of medical progress. As Fonseca et al. (2021) point out in their conclusions, their modelling of medical progress as a reduction in the marginal cost of health improvements rules out sizeable effects on health care spending due to the expansion of treatments. This stands in contrast to our formulation where, by raising the marginal effectiveness of health care, medical progress induces an increase in the demand for it (see e.g. Baker et al., 2003; Cutler and Huckman, 2003; Wong et al., 2012; Roham et al., 2014). With demand expansion acting as a lever, the individual drivers of spending growth have a greater propensity to reinforce each other and, thus, exhibit stronger complementarity.

[38] 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).

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

[40] See Acemoglu and Guerrieri (2008) and Frankovic et al. (2020a) for an analytical representation of this mechanism.

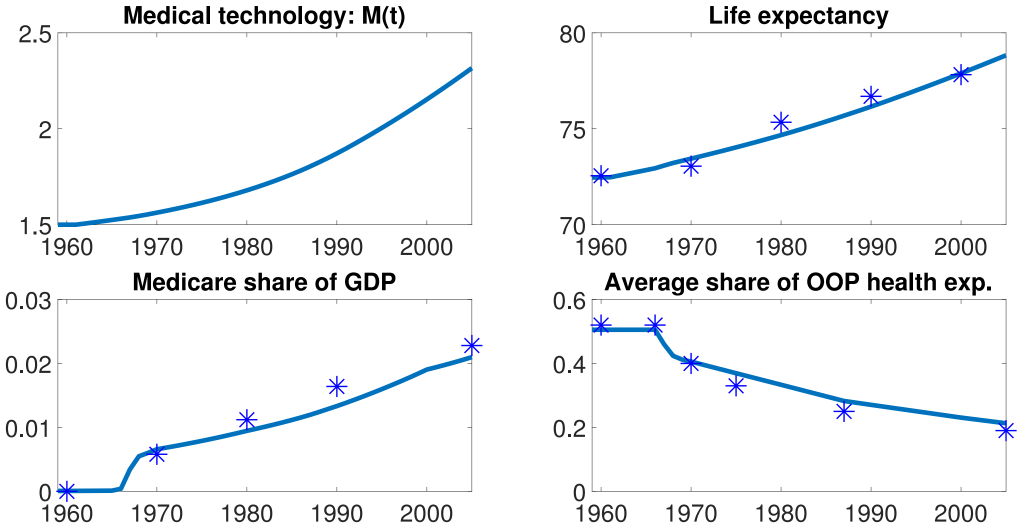

Fig. 5. Medical technology, life expectancy, Medicare share of GDP and the average share of out-of-pocket (OOP) health expenditures.

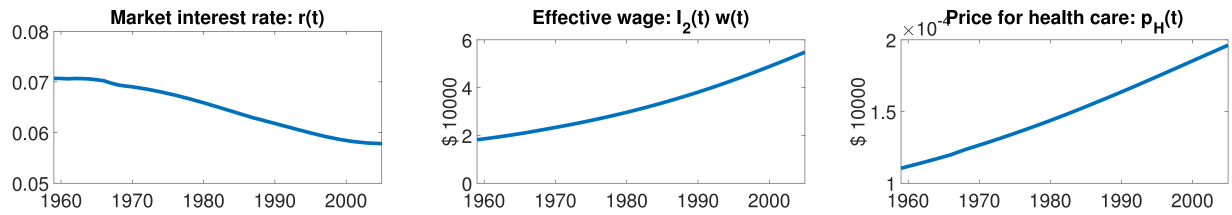

Fig. 6. Prices in the benchmark scenario.

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 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 4.1). 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 (see Section 4.2). 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. 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 red, dashed plot). Thus, we hold public and private health insurance rates constant from 1965 onwards. Fig. 7 shows a much slower growth rate of per capita health expenditure in the counterfactual. A comparison with the benchmark shows that the expansion of health insurance explains about 63% of the spending increase between 1965 and 2005 and about 59% of the increase between 1965 and 1990.

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 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 per capita.

Fig. 8 reveals a much slower progress of medical technology in the counterfactual. This is because the absence of large-scale health insurance programmes 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 57% increase in the rate of medical progress over the time span 1965 to 2005. For the time span 1965 to 1990 we find an increase

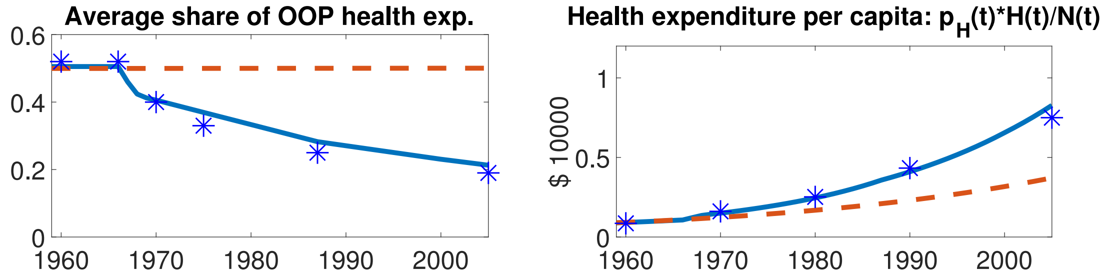

Fig. 7. Average share of out-of-pocket (OOP) expenditure and health expenditure per capita in the benchmark (blue, solid) and the counterfactual reflecting constant 1965 insurance level (red, dashed).

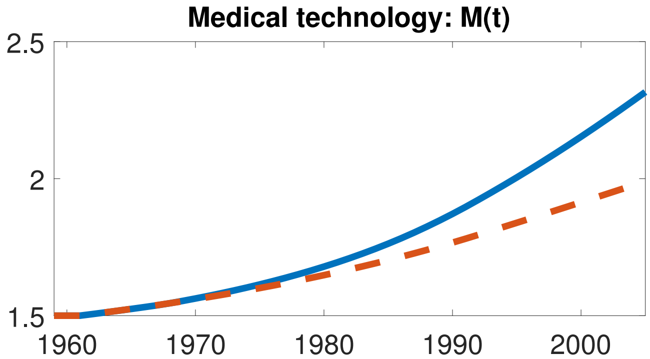

Fig. 8. Medical technology in the benchmark (blue, solid) and the counterfactual reflecting constant 1965 insurance level (red, dashed).

in the rate of medical progress by 39%, a figure that is close in magnitude to the 20%–30% increase in medical equipment and device patenting over the same time span that Clemens and Olsen (2021) estimate as an outcome of the introduction of Medicare/Medicaid. 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 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 (comments on the individual life-cycle outcomes are contained in Appendix E). As Fig. 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 capital accumulation: Here, the more pronounced increase in life expectancy from 72.5 years in 1965 to 78.9 years in 2005 in the benchmark as opposed to only 77.7 years in the counterfactual induces a reallocation of expenditures to higher ages and, consequently, to additional savings. Surprisingly perhaps, the expansion of health insurance dampens the expansion over time of the average value of life across the population. 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 (25)–(27)], its higher rate of growth in the counterfactual reflects stronger consumption growth. At the same time, the optimal choice of health care implies that the value of life equals the price of survival [see (24)].[41] As it turns out, the latter is facing a weaker incline in the benchmark relative to the counterfactual both due to the ongoing reduction in

[41] See Frankovic et al. (2020a) for a more elaborate discussion of the relationship between the value of life and the price of survival (or effective price of medical care). One key take-away is that the value of life can be interpreted as the marginal rate of substitution between survival at (a, t) which for an optimal allocation is equated with the price of survival (as measured in units of the consumption good). Notably, both the expansion of health insurance and the medical progress thus induced tend to lower the price of survival. The fact that the value of life is *lower* in the benchmark scenario as compared to the counterfactual at each point in time is then reflecting the lower price of survival and the ensuing shift in the allocation towards health care. Conversely, one could argue that the higher value of life in the counterfactual scenario is indicative of an unmet demand for survival. This in turn is mirroring the fact that the expansion of health insurance is generating an unambiguous increase in welfare for all cohorts, as will be shown in Section 4.3.

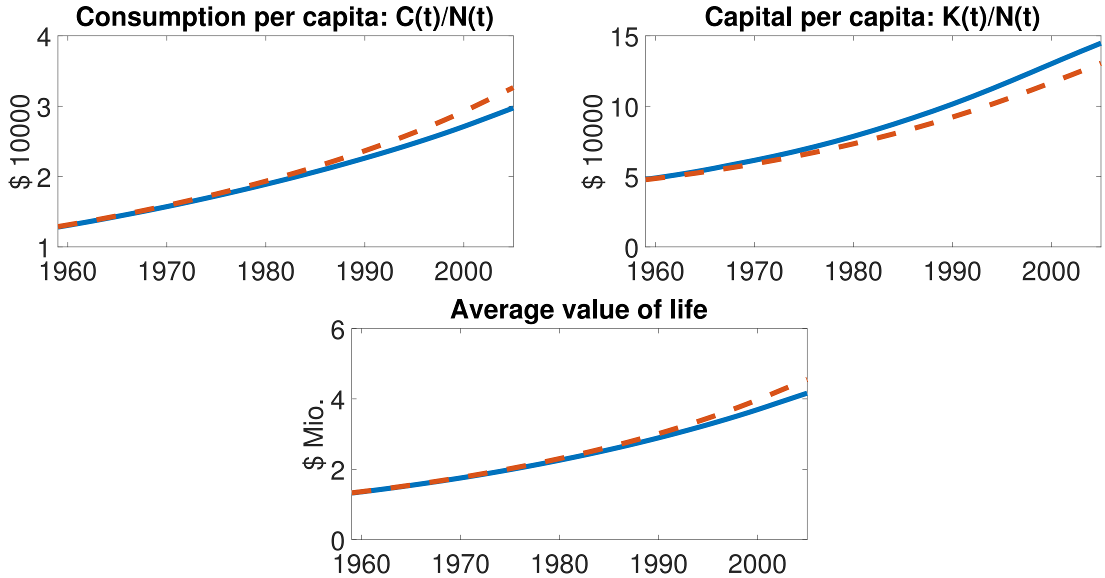

Fig. 9. Per capita values of consumption and capital and the population-weighted average value of life in the benchmark (blue, solid) and the counterfactual (red, dashed).

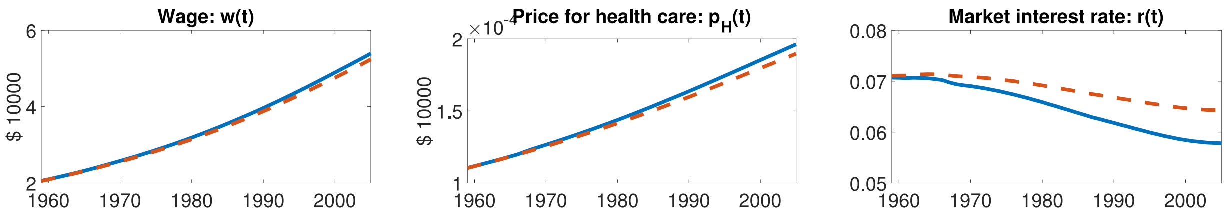

Fig. 10. Prices in the benchmark (blue, solid) and the counterfactual reflecting constant 1965 insurance level (red, dashed).

co-payments and due to the increase in medical effectiveness.[42] These two trends dampen the higher rate of medical price inflation in the benchmark by enough to induce a slower increase.

Finally, Fig. 10 illustrates the impact of the health insurance expansion on prices. Lesser growth in the health care sector in the counterfactual scenario is reflected in a lower rate 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 half a percentage point higher. This wedge is reflecting the gap in life expectancy and, thus, the lower degree of capital accumulation in the counterfactual scenario.

4.2. 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, from the spending impact that arises through the stimulation of medical innovation.[43] In order to separate the two channels we now simulate the effect of the benchmark insurance expansion for a scenario in which the state of technology is assumed to develop according to the main counterfactual. This scenario, depicting the moral hazard channel, is illustrated by the orange, dotted plot in Fig. 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

[42] The fact that survival/quality-adjusted medical prices are declining or increasing only modestly is well documented (e.g. Cutler et al., 1998; Dunn, 2012; Lakdawalla et al., 2015; Hult et al., 2018).

[43] Recall that we employ the term “moral hazard” here in the sense that health insurance generates excessive consumption by lowering the consumer price of health care below its value in competitive equilibrium (see Zweifel and Manning, 2000). The moral hazard effects we measure here are to be understood at general equilibrium level, involving price adjustments as well as adjustments in the age structure of the population.

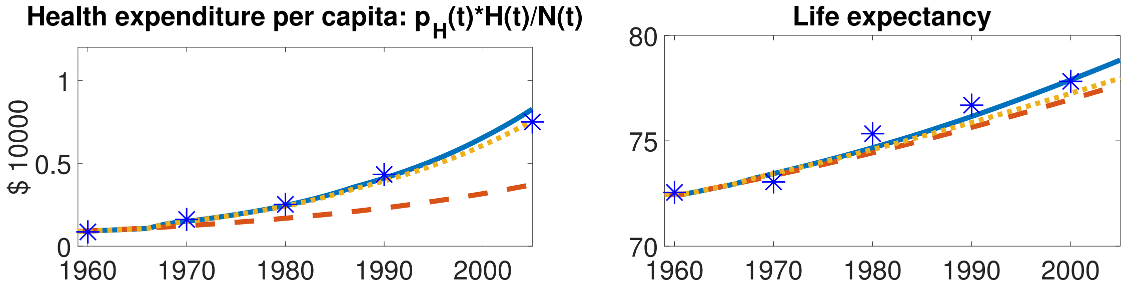

Fig. 11. Health expenditure per capita and life expectancy in (i) the benchmark (blue, solid); (ii) the main counterfactual without insurance expansion (red, dashed); (iii) the counterfactual with insurance expansion but without insurance-induced medical change (orange, dotted).

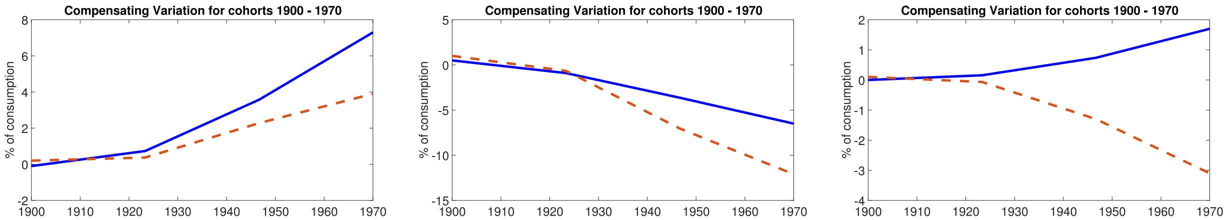

Fig. 12. Compensating variation for induced medical progress only (left), moral hazard only (centre) and total impact (right).

have switched off in this scenario. Overall, we find that about 85% of the additional spending in 2005 that is due to the expansion of health insurance can be attributed to moral hazard, whereas the remaining 15% can be attributed to induced medical progress.[44]

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 1.2 years of life expectancy in the year 2005 (78.9 years in the benchmark scenario as opposed to 77.7 in the main counterfactual). We find that 0.9 years of this increase are due to induced-medical 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 has led to more than a doubling of health care expenditure over the time span 1965–2005 suggests the scope for a substantial welfare loss. This should particularly hold within our stylized model, in which health care expenditures are deterministic so that 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 consider for the birth cohorts 1900–1970 a set of compensating variation exercises in the spirit of Weil (2014), Jones and Klenow (2016) and Frankovic et al. (2020b). These exercises are depicted in Fig. 12 where for the moment we focus on the blue, solid plots that represent a setting in which productivity grows in line with the benchmark scenario.

Specifically, we consider by what proportion we would need to augment the life-cycle consumption of the 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).

Our analysis reveals that both the medical progress and the excess consumption of health care that are induced by the expansion of health insurance yield sizeable welfare effects. As one would expect, induced medical innovations per se yield benefits for all cohorts which increase, however, with the progression of the birth year (left panel). Cohorts born after 1900 would require increasing

[44] With induced medical progress explaining 18% of the spending increase from the insurance expansion and this, in turn, explaining 63% of the overall spending increase, we find that insurance-induced medical progress explains about 11% 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).

shares of their respective consumption level to be added in order to compensate for the absence of medical progress, this share reaching 7.3% for the 1970 birth cohort. The opposite holds for moral hazard, where successive birth cohorts face increasing welfare losses up to the 1970 cohort which would be willing to give up around 6.5% of their consumption in order to forego the moral hazard associated with the health insurance expansion (middle panel). Notably, both the benefits from medical innovation and the welfare loss associated with moral hazard exhibit cumulative effects, which are both linked to the expanding size of the health care industry. Whereas an expanding health care sector boosts the growth of the medical innovation sector over time, it also induces stronger distortions from the ongoing expansion of health insurance. Combining the two offsetting impacts on welfare, we find that the expansion of health insurance has triggered a modest welfare gain for all cohorts, which increases up to an equivalent variation of 1.7% of the life-cycle consumption for the 1970 cohort.

From a different angle, our results show that the subsidization of health care expenditure that is implied by health insurance 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 gains in survival and productivity.[45] With the direction of the externality, thus, flowing from older to younger (or yet unborn) generations there is an issue about how early born 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 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 all 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).

4.4. The role of income growth

One 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; Chen et al., 2021). This argument extends to the assessment 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.[46]

Given this, one may wonder whether health insurance expansion would still be beneficial within a stagnating economy. For this purpose we consider a last counterfactual scenario in which we study the impact of health insurance expansion under the assumption that total factor productivity stagnates at the 1965 level in both the final goods and the health care sector, i.e. $A_j(t) \equiv A_j(1965)$ for $j = Y, H$.[47] Fig. 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 (red, dashed 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 consumption.[48] The latter trend is mirrored in the stagnation of the average value of life over time. As expected, the trade-off between health care and consumption has much more bite in the absence of productivity growth.

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 calculate the compensating variation relating to the isolated effects of (i) insurance-induced medical progress and (ii) moral hazard, as well as (iii) their combined effects, but now under the assumption of constant productivity at the 1965 level. The results for the birth cohorts 1900–1970 are depicted in Fig. 12 as red, dashed plots. As expected, we now find much weaker gains to induced medical progress, leading to a maximum equivalent variation of 3.9% for the 1970 cohort. Likewise the excessive consumption of health care due to the expansion of health insurance tends to trigger a much stronger loss for late-born cohorts, reaching a consumption equivalent of -12.1% for the 1970 cohort. Unsurprisingly, the combined welfare effect of the insurance expansion now turns out to be negative for most cohorts, reaching up to -3.1% for the 1970 cohort. Hence, we can conclude that income growth has played a key role for the unambiguously positive impact of the US health insurance expansion on welfare. One could then view the expansion of health insurance as an appropriate if second-best policy response (wittingly or not) to the income growth in the US.

Two aspects of the welfare effect of excessive health care spending in the absence of income growth are worth of note. First, there is a sizeable gain from health insurance for the earliest-born cohorts, amounting to a willingness to pay for health insurance of 1% of life-time consumption for the 1900 birth cohort. This illustrates the potential for early-born cohorts to benefit from excessive health insurance as a compensation for their inducement of medical progress to the advantage of later-born cohorts. Second, while

[45] 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 subsidization 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.

[46] 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.

[47] In addition, we fix pension benefits at their 1965 level.

[48] Note that some GDP growth can be sustained through the health-related productivity increase.

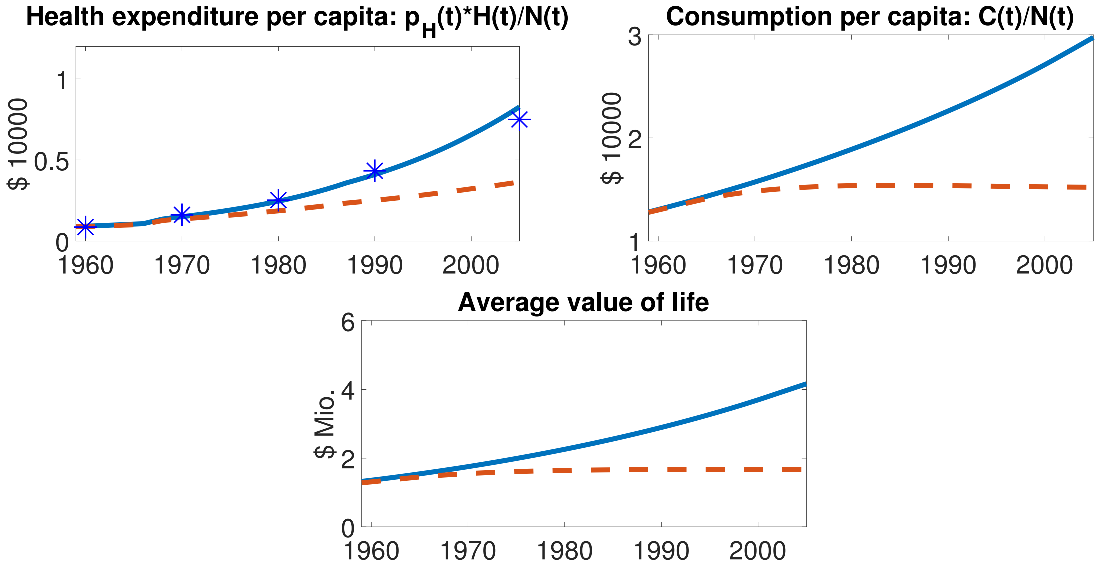

Fig. 13. Benchmark (blue, solid) and "productivity stagnation" counterfactual (red, dashed).

later-born cohorts are facing losses from the excessive consumption of health care in the absence of medical progress that exceed the pure gains from medical progress by a large margin, the combined effect is much weaker (see the numbers for the 1970 cohort reported above). This illustrates that the partial compensating variation terms are not additive, the reason being that induced medical progress renders the otherwise excessive health care spending more effective in lowering mortality. This implies a weakening of the loss from moral hazard or, conversely, a further leveraging of the gains from induced medical progress when it comes to the overall assessment of welfare.

We conclude by noting that both the gradient in the compensating variation for moral hazard and the lack of additivity of the partial compensating variation terms for medical progress and moral hazard are much less pronounced in the presence of income growth. This is indicative of the strong role that income growth plays in mitigating the trade-off between health care spending and consumption.

5. Conclusion

We have studied the macroeconomic impact of the health insurance expansion in the US between 1965 and 2005, taking account not only the direct effect through decreases in out-of-pocket 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 à la Baumol (1967) and medical progress itself.

We find that the expansion of health insurance explains about 63 percent of the increase in health care expenditure between 1965 and 2005 and boosts the growth rate of medical R&D by about 57 percent. 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 85 percent of the spending increase with the remaining 15 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 1.2 years in 2005, only 0.3 years are attributable to the higher health care expenditure associated with moral hazard, whereas 0.9 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.

Compensating variation exercises for the cohorts born in the years 1900–1970 show that while the moral hazard associated with the expansion of health insurance creates welfare losses for all but the very early born cohorts, the gains in life expectancy and productivity from the induced medical progress more than compensate for this, leading to modest 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 *current* health care spending that by stimulating medical progress yields *future* gains in life expectancy. However, this does not hold true in the absence of productivity-driven income growth as a driver of an increasing willingness to pay for longevity-enhancing innovations. Here, it would need to be shown that the direct value of insurance expansion would be sufficient to overcompensate the burden.

While our results speak to a dynamic role of health insurance that extends well beyond the benefits from risk sharing, they also suggest there may be more efficient ways for stimulating medical progress. By avoiding the distortion through excessive health care spending the direct subsidization of R&D activity, for instance, may prove a more appropriate tool that could yield welfare gains even under weak income growth. Frankovic et al. (2020b) consider the subsidization of innovative health care for the purpose of boosting the diffusion process and show that while such subsidies are generally effective, the unequal distribution of the resulting benefits across generations requires careful consideration on the financing side to allow for Pareto efficient solutions.

Our approach involves a number of stylizations for the purpose of keeping the analysis tractable. First, by following Ford et al. (2006), Cutler (2008), Buxbaum et al. (2020) and Fonseca et al. (2021) and assuming that about 50 percent of the increase in longevity is related to medical treatments we are taking a conservative stance on the scope for medical progress to improve welfare. This is because we are neglecting the impact of medical progress in lowering morbidity and, thus, enhancing the quality of life, an effect that is considered in Böhm et al. (2021). Our robustness analysis in Appendix F (see Figure 5) suggests that while the benefits from medical progress are understated, the consideration of morbidity reductions does not have a great bearing on our main findings regarding the role of health insurance expansion. Second, while our modelling of a cohort representative consumer allows us to study intergenerational differences in behaviours and outcomes, it bunches cross cohort heterogeneity in social status or health status into an average. This may, indeed, imply that we are underestimating the demand and welfare impact of health insurance expansion, which we would expect to disproportionately enhance access to health care by groups that are in particular need.[49] Third, we are abstracting from ex-ante moral hazard, i.e. the incentive for individuals to invest too little in the prevention of adverse health events when they are covered by health insurance. Cole et al. (2019) show that ex-ante moral hazard creates a similar tendency towards the overconsumption of health care that is associated with a macroeconomic welfare loss. In line with Bhattacharya and Packalen (2012) we would argue, however, that by expanding the demand for health care, ex-ante moral hazard then creates a similar dynamic incentive for undertaking medical R&D and, thereby, reduce the underinvestment due to the dynamic externality. Third, we have abstracted from imperfections in the diffusion of new medical technology. Frankovic et al. (2020b) show (i) that a lag in the (widespread) adoption of state-of-the-art medical technology creates a welfare loss in its own right and (ii) that the expansion of the health care market facilitates diffusion. In summary, these considerations suggest that our results constitute a lower bound on the benefits from expanding health insurance. This would seem to hold all the more if the direct value of health insurance was accounted for. The recent finding by Jung and Tran (2022) that an expansion of US health insurance towards universal coverage has the scope to increase welfare suggests this is likely to be the case.

A second set of limitations relates to the modelling of institutional structures. This applies in particular to the process of medical R&D and the incentives involved from an industrial economic perspective. We have argued in Section 2.3 why we believe our reduced form to embrace the key features of the R&D process, but we appreciate that a more detailed modelling of e.g. the role of patent protection in this process may yield insights into alternative or accompanying policies to enhance medical progress. A second point relates to the more nuanced modelling of different types of health care (ambulatory, hospital, pharmaceutical), including the context of their provision, which we would expect to bear on the demand for medical innovations as well as on their adoption (e.g. Chandra and Skinner, 2012; Skinner and Staiger, 2015; Clemens and Olsen, 2021).[50] A third limitation relates to the more detailed modelling of the financing side. This relates in particular to the modelling of the structure of US health insurance contracts itself, as well as the various reforms that were underlying the process of expansion, which would have had a bearing on the extent, timing and direction of R&D stimuli. By considering non-distortionary taxes, we may be overestimating to some extent the welfare impact of the health insurance expansion. Further issues emerge when considering the drivers of medical progress and its consequences within the more extensive European welfare systems with their greater reliance on publicly provided and/or financed health care (Böhm et al., 2021; Kelly and Kuhn, 2022). We leave a further exploration of these topics to future research.

CRediT authorship contribution statement

Ivan Frankovic: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing. **Michael Kuhn:** Conceptualization, Methodology, Formal analysis, Investigation, Writing, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

---

[49] In a similar framework with exogenous medical progress, Frankovic and Kuhn (2019) demonstrate that medical progress tends to disproportionately benefit those with higher socio economic status if it is not accompanied by an increase in the access to the effective use of health care on the part of those with lower socio economic status.

[50] Chandra and Skinner (2012) provide evidence for large variance in the adoption patterns of both cost-effective and in many cases cost-ineffective innovations. That many technologies may, in fact, be poorly effective is reflected in our macroeconomic setting by the mortality elasticity in respect to health care being rather low in comparison to settings where health care is known to be effective in lowering mortality, such as spending on circulatory disease and cancer programmes in the UK NHS (Martin et al., 2008).

Appendix. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jhealeco.2022.102717.

References

Abeliansky, AL., Strulik, H., 2018. How we fall apart: Similarities of human aging in 10 European countries. Demography 55, 341–359.
Acemoglu, D., Finkelstein, A., 2008. Input and technology choices in regulated industries: evidence from the US health care sector. J. Polit. Econ. 116, 837–880.
Acemoglu, D., Finkelstein, A., Notowidigdo, MJ., 2013. Income and health spending: evidence from oil price shocks. Rev. Econ. Stat. 95, 1079–1095.
Acemoglu, D., Guerrieri, V., 2008. Capital deepening and nonbalanced economic growth. J. Polit. Econ. 116, 467–498.
Acemoglu, D., Linn, J., 2004. Market size in innovation: theory and evidence from the pharmaceutical industry. Q. J. Econ. 119, 1049–1090.
Aksoy, Y., Basso, HS., Smith, RP., Grasl, T., 2019. Demographic structure and macroeconomic trends. Am. Econ. J.: Macroecon. 11, 193–222.
Andersen, TM., Bhattacharya, J., 2017. The intergenerational welfare state and the rise and fall of pay-as-you-go pensions. Econom. J. 127, 896–923.
Aron-Dine, A., Einav, L., Finkelstein, A., 2013. The RAND health insurance experiment, three decades later. J. Econ. Perspect. 27, 197–222.
Baicker, K., Goldman, D., 2011. Patient cost-sharing and medical spending growth. J. Econ. Perspect. 25, 47–68.
Baker, LC., 2001. Managed care and technology adoption in health care: evidence from magnetic resonance imaging. J. Health Econ. 20, 395–421.
Baker, L., Birnbaum, H., Geppert, J., Mishol, D., Moyneur, E., 2003. The relationship between technology availability and health care spending. Health Aff. - Web Exclus..
Baker, LC., Phibbs, CS., 2002. Managed care, technology adoption, and health care: the adoption of neonatal intensive care. Rand J. Econ. 33, 524–548.
Baumol, WJ., 1967. Macroeconomics of unbalanced growth: the anatomy of urban crisis. Amer. Econ. Rev. 57, 415–426.
Bhattacharya, J., Packalen, M., 2012. The other ex-ante moral hazard in health. J. Health Econ. 31, 135–146.
Bilodeau, D., Cremieux, P-Y., Jaumard, B., Ouellette, P., Vovor, T., 2004. Measuring hospital performance in the presence of quasi-fixed inputs: an analysis of Quebec hospitals. J. Product. Anal. 21, 183–199.
Bilodeau, D., Cremieux, P-Y., Ouellette, P., 2000. Hospital cost functions in a non-market health care system. Rev. Econ. Stat. 82, 489–498.
Bloom, DE., Canning, D., Mansfield, RK., Moore, M., 2007. Demographic change, social security systems, and savings. J. Monet. Econ. 54, 92–114.
Böhm, S., Grossmann, V., Strulik, H., 2021. R & D-driven medical progress, health care costs, and the future of human longevity. J. Econ. Ageing 18, 100286.
Boldrin, M., Montes, A., 2005. The intergenerational state: education and pensions. Rev. Econom. Stud. 72, 651–664.
Buxbaum, JD., Chernew, ME., Fendrick, AM., Cutler, DM., 2020. Contributions of public health, pharmaceuticals, and other medical care to us life expectancy changes, 1990–2015. Health Aff. 39, 1546–1556.
Chandra, A., Finkelstein, A., Sacarny, A., Syverson, C., 2016. Health care exceptionalism? Performance and allocation in the US health care sector. Amer. Econ. Rev. 106, 2110–2144.
Chandra, A., Skinner, J., 2012. Technology growth and expenditure growth in health care. J. Econ. Lit. 50, 645–680.
Chen, S., Kuhn, M., Prettner, K., Bloom, DE., Wang, C., 2021. Macro-level efficiency of health expenditure: Estimates for 15 major economies. Soc. Sci. Med. 287, 114270.
Chernew, ME., Newhouse, JP., 2011. Health care spending growth. In: Pauly, MV., Barros, PG. (Eds.), Handbook of Health Economics, Vol. 2. Elsevier, chapter 15.
Chetty, R., 2006. A new method of estimating risk aversion. Amer. Econ. Rev. 96, 1821–1834.
Clemens, J., 2013. The Effect of US Health Insurance Expansions on Medical Innovation. NBER Working Paper 19761.
Clemens, J., Olsen, M., 2021. Medicare and the Rise of American Medical Patenting: The Economics of User-Driven Innovation. CES-Ifo Working Paper. 9008.
Cole, HL., Kim, S., Krueger, D., 2019. Analyzing the effects of insuring health risks. Rev. Econom. Stud. 86, 1123–1169.
Conesa, JC., Costa, D., Kamali, P., Kehoe, TJ., Nygard, VM., Raveendranathan, G., Saxena, A., 2018. Macroeconomic effects of medicare. J. Econ. Ageing 11, 27–40.
Costa, DL., Kahn, ME., 2004. Changes in the value of life, 1940-1980. J. Risk Uncertain. 29, 159–180.
Cremieux, P-Y., Ouellette, P., Rimbaud, F., Vigeant, S., 2005. Hospital cost flexibility in the presence of many outputs: a public–private comparison. Health Care Manage. Sci. 8, 111–120.
Cutler, DM., 2008. Are we finally winning the war on cancer? J. Econ. Perspect. 22, 3–26.
Cutler, DM., Huckman, RS., 2003. Technological development and medical productivity: the diffusion of angioplasty in New York State. J. Health Econ. 22, 187–217.
Cutler, DM., McClellan, M., Newhouse, JP., Rehmer, D., 1998. Are medical prices declining? Evidence from heart attack treatments. Q. J. Econ. 113, 991–1024.
Dalgaard, C-J., Strulik, H., 2014. Optimal aging and death: Understanding the preston curve. J. Eur. Econom. Assoc. 12, 672–701.
De Nardi, M., French, E., Jones, JB., 2010. Why do the elderly save? The role of medical expenses. J. Polit. Econ. 118, 39–75.
Dubois, P., de Mouzon, O., 2015. Market size and pharmaceutical innovation. Rand J. Econ. 46, 844–871.
Dunn, A., 2012. Drug innovations and welfare measures computed from market demand: The case of anti-cholesterol drugs. Am. Econ. J.: Appl. Econ. 4, 167–189.
Eichner, MJ., 1998. The demand for medical care: what people pay does matter. Am. Econ. Rev. 88 (Papers & Proceedings), 117–121.
Faere, R., Grosskopf, S., Lindgren, B., Poullier, J-P., 1997. Productivity growth in health-care delivery. Med. Care 35, 354–366.
Feldstein, M., 1971. Hospital cost inflation: a study of nonprofit price dynamics. Amer. Econ. Rev. 61, 853–872.
Feldstein, M., 1977. Quality change and the demand for hospital care. Econometrica 45, 1681–1702.
Fernandez-Villaverde, J., Krueger, D., Ludwig, A., Schön, M., 2018. An Endogenous Growth Model with a Health Sector. Mimeo.
Finkelstein, A., 2004. Static and dynamic effects of health policy: evidence from the vaccine industry. Q. J. Econ. 119, 527–564.
Finkelstein, A., 2007. The aggregate effects of health insurance: evidence from the introduction of medicare. Q. J. Econ. 122, 1–35.
Finkelstein, A., McKnight, R., 2008. What did medicare do? The initial impact of medicare on mortality and medical out-of-pocket spending. J. Public Econ. 92, 1644–1668.
Fonseca, R., Michaud, P-C., Kapteyn, A., Galama, T., 2021. Accounting for the rise of health spending and longevity. J. Eur. Econom. Assoc. 19, 536–579.
Ford, ES., Ajini, UA., Croft, JB., Critchley, JA., Labarth, DR., Kotte, TE., Giles, WH., Capewell, S., 2006. Explaining the decrease in U.S. deaths from coronary disease, 1980-2000. N. Engl. J. Med. 356, 2388–2398.
Frankovic, I., Kuhn, M., 2019. Access to health care, medical progress and the emergence of the longevity gap: A general equilibrium analysis. J. Econ. Ageing 14, 100188.
Frankovic, I., Kuhn, M., Wrzaczek, S., 2020a. On the anatomy of medical progress within an overlapping generations economy. Economist 168, 215–257.
Frankovic, I., Kuhn, M., Wrzaczek, S., 2020b. Medical innovation and its diffusion: Implications for economic performance and welfare. J. Macroecon. 66, 103262.
Gallet, CA., Doucouliagos, H., 2017. The impact of health care spending on health outcomes: a meta-regression analysis. Soc. Sci. Med. 179, 9–17.
Hall, RE., Jones, CI., 2007. The value of life and the rise in health spending. Q. J. Econ. 122, 39–72.
Hult, KJ., Jaffe, S., Philipson, TJ., 2018. How does technological change affect quality-adjusted prices in health care? Systematic evidence from thousands of innovations. Am. J. Health Econ. 4, 433–453.
Jones, CI., 2016. Life and growth. J. Polit. Econ. 124, 539–578.

Jones, CI., Klenow, PJ., 2016. Beyond GDP? Welfare across countries and time. Amer. Econ. Rev. 106, 2426–2457.
Jung, J., Tran, C., 2016. Market inefficiency, insurance mandate and welfare: U.S. health care reform 2010. Rev. Econ. Dyn. 20, 132–159.
Jung, J., Tran, C., 2022. Social health insurance: a quantitative exploration. J. Econom. Dynam. Control 139, 104374.
Kelly, M., 2020. Medicare for all or medicare for none? A macroeconomic analysis of health care reform. J. Macroecon. 63, 103170.
Kelly, M., Kuhn, M., 2022. Congestion in a public health service: a macro approach. Journal of Macroeconomics 74, 103451.
Koijen, RSJ., Philipson, TJ., Uhlig, H., 2016. Financial health economics. Econometrica 84, 195–242.
Kotschy, R., 2021. Health dynamics shape life-cycle incomes. J. Health Econ. 75, 102398.
Kowalski, AE., 2015. Censored quantile instrumental variable estimates of the price elasticity of expenditure on medical care. J. Bus. Econom. Statist. 34, 107–117.
Kuhn, M., 2022. Medical progress, aging, and sustainability of health care finance. In: Bloom, DE., Sousa-Poza, A., Sunde, U. (Eds.), Handbook of the Economics of Ageing. Routledge, forthcoming.
Kuhn, M., Prettner, K., 2016. Growth and welfare effects of health care in knowledge based economies. J. Health Econ. 46, 100–119.
Kuhn, M., Wrzaczek, S., Prskawetz, A., Feichtinger, G., 2011. Externalities within a life cycle model with endogenous survival. J. Math. Econom. 47, 627–641.
Kuhn, M., Wrzaczek, S., Prskawetz, A., Feichtinger, G., 2015. Optimal choice of health and retirement in a life-cycle model. J. Econ. Theory 158A, 186–212.
Kyle, MK., McGahan, AM., 2012. Investments in pharmaceuticals before and after TRIPS. Rev. Econ. Stat. 94, 1157–1172.
Lakdawalla, D., Shafrin, J., Lucarelli, C., Nicholson, S., Khan, ZM., Philipson, T., 2015. Quality-adjusted cost of care: a meaningful way to measure growth in innovation cost versus the value of health gains. Health Aff. 34, 555–561.
Manning, WG., Newhouse, JP., Duan, N., Emmett, BK., A., Leibowitz., Marquis, MS., 1987. Health insurance and the demand for medical care: Evidence from a randomized experiment. Amer. Econ. Rev. 77, 251–277.
Martin, S., Rice, N., Smith, PC., 2008. Does health care spending improve health outcomes? Evidence from English programme budgeting data. J. Health Econ. 27, 826–842.
Murphy, KM., Topel, RH., 2006. The value of health and longevity. J. Polit. Econ. 114, 871–904.
Newhouse, JP., 1992. Medicare care costs: How much welfare loss? J. Econ. Perspect. 6, 3–21.
Ouellette, P., Vierstraete, V., 2004. Technological change and efficiency in the presence of quasi-fixed inputs: a DEA application to the hospital sector. European J. Oper. Res. 154, 755–763.
Rockwood, K., Mitnitski, A., 2007. Frailty in relation to the accumulation of deficits. J. Gerontol.: Med. Sci. 62A, 722–727.
Roham, M., Gabrielyan, AR., Archer, NP., Grignon, ML., Spencer, BG., 2014. The impact of technological intensity of service provision on physician expenditures: an exploratory investigation. Health Econ. 23, 1224–1241.
Romer, PM., 1990. Endogenous technological change. J. Polit. Econ. 98 (5, Part 2), S71–S102.
Schneider, MT., Winkler, R., 2021. Growth and welfare under endogenous lifetimes. ScandInavian Journal of Economics 123 (4), 1339–1384.
Scott Morton, F., Kyle, M., 2012. Markets for pharmaceutical products. In: MV, Pauly, Barros, PG (Eds.), Handbook of Health Economics, Vol. 2. Elsevier, chapter 12.
Skinner, J., Staiger, D., 2015. Technology diffusion and productivity growth in health care. Rev. Econ. Stat. 97 (5), 951–964.
Spitalnic, P., Heffler, S., Dickensheets, B., Knight, M., 2016. Hospital Multifactor Productivity: An Updated Presentation of Two Methodologies. Office of the Actuary, Centers for Medicare & Medicaid Services, U.S. Department of Health and Human Services, https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/ReportsTrustFunds/Downloads/ProductivityMemo2016.pdf.
Suen, RMH., 2009. Technological Advance and the Growth in Health Care Spending. Mimeo.
Thomas, LG., 1996. Industrial policy and international competitiveness in the pharmaceutical industry. In: Helms, RB (Ed.), Competitive Strategies in the Pharmaceutical Industry. aEI Press, Washington, pp. 107–129.
Weil, DN., 2014. Health and economic growth. In: Aghion, P., Durlauf, SN. (Eds.), Handbook of Economic Growth, Vol. 2B. Elsevier, chapter 3.
Weisbrod, B., 1991. The health care quadrilemma: an essay on technological change, insurance, quality of care, and cost containment. J. Econ. Lit. 29, 523–552.
Wong, A., Wouterse, B., Slobbe, LCJ., Boshuizen, HC., Polder, JJ., 2012. Medical innovation and age-specific trends in health care utilization: findings and implications. Soc. Sci. Med. 74, 263–272.
Zhao, K., 2014. Social security and the rise in health spending. J. Monetary Econ. 64, 21–37.
Zweifel, P., Manning, WG., 2000. Moral hazard and consumer incentives in health care. In: Culyer, AC., Newhouse, JP. (Eds.), HandBook of Health Economics, Vol. 1A. Elsevier, (chapter 8).