‘Healthy’ Business Cycle*

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A macro-health model with endogenous survival probability dependent on health history builds in a real business cycle framework three channels of endogenous health accumulation documented in various scientific disciplines: 1) health affects utility; 2) health affects productivity but depreciates with production; and 3) health is maintained with medical care or leisure activity. The model generates procyclical health expenditure and countercyclical life expectancy, in line with data, and other aggregate properties seen in the RBC literature. All three channels work to the right direction in matching observables, and their interactions also play roles in improving the model's quantitative fit.

Keywords: Business cycle; Life expectancy; Health expenditure; Time allocation

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1 Introduction

Relationship between health and macroeconomy has received increasing attention. Issues concerning a nation's general health status and health expenditure take a center stage in recent macroeconomic analyses and policy forums.[1] Jones and Klenow (2016) show the importance of national health for welfare analysis (see, also, Murphy and Topel, 2006; Hall and Jones, 2007), while a growing literature explores macroeconomic causes and implications of the long-run trend in health expenditure.[2] Relationship between national health and macroeconomic development is at the core of the World Health Organization Commission on Macroeconomics and Health. National health is also a key measure of macroeconomic development in the United Nations Human Development Index (HDI).

Empirical evidence shows a positive relationship between health and long-run growth. In contrast, for industrialized economies, general national health status tends to be negatively correlated with macroeconomic performance in the short run, improving in recessions and worsening in booms, even though health expenditure generally declines during contractions and rises during expansions. Egan et al. (2017) stress the critical importance of such short-run correlations for business-cycle studies.

This paper studies the causes for the cyclical correlations of national health status and health expenditure with macroeconomic performance, particularly, the joint presence of procyclical health expenditure but countercyclical life expectancy, which are key features of the data that a satisfactory macro-health business-cycle model should account for. To this end, we build in an RBC framework endogenous survival probability dependent of health history, and three channels of endogenous health accumulation suggested by various scientific disciplines, including health economics, biomedical science, public health, psychobiology, biosociology, and environmental economics: 1) health affects utility (utility channel); 2) health affects productivity but depreciates with production (production channel); and 3) health is maintained with medical care or leisure activity (time channel). This provides a unified framework for analyzing the cyclical properties of national health status and health expenditure using the language and tools of modern dynamic macroeconomics. The structural approach allows us to decompose the contributions of the three channels

[1] According to recent polls from Gallup and in recent headline news, the confluence between health care and macroeconomy tops America's "most important problem" list.

[2] See, among others, Hall and Jones (2007), Zhao (2014), and Halliday et al. (2019). Jung and Tran (2016) study welfare effects of health care reforms while Fang and Gavazza (2011) and Huang and Huffman (2014) analyze welfare and labor market implications of employment-based health benefits in the US. More recently, Cole et al. (2019) analyze the tradeoff of health-related social insurance on risk-sharing against dynamic disincentive effect of health investment.

to generating business-cycle moments for national health variables and other macroeconomic measures of interest, and to quantify the roles of interactions among these channels of endogenous health accumulation.

Our structural model calibrated to US data does a good job in explaining the joint cyclical behaviors of national health input and output. In particular, the model generates procyclical health expenditure and countercyclical life expectancy, while it accounts for a majority of the standard deviations of these two health variables. In accounting for the cyclical behaviors of traditional macroeconomic variables, the model performs similarly as the standard RBC model.

Results from our structural decomposition exercises suggest that each of the three channels works in the right direction in explaining the cyclical behaviors of national health expenditure and life expectancy, as well as in matching other moments of data concerning the cyclical behaviors of traditional macroeconomic variables, and their interactions also play a role in improving the model's quantitative fit with data.

This is related to another contribution of the paper. In the tradition of the seminal work of Grossman (1972) that emphasizes a consumption value of health, the growing literature of macro-health models have mostly incorporated the consumption channel of health accumulation. In contrast, this literature has paid much less attention to the production channel and almost none to the time channel. The results in this paper suggest that, at least for business-cycle studies, the production and time channels could also play important roles in matching the cyclical behaviors of national health variables, as well as other aggregate properties studied in the RBC literature.

2 Empirical evidence

2.1 *Procyclical national health expenditure but countercyclical national health status*

Life expectancy as a basic measure of a nation's general health status presented in HDI is a crucial component of economic wellbeing for the nation's population. Recent macroeconomic studies have incorporated life expectancy as a key dimension in long-term welfare analysis (e.g., Nordhaus, 2003; Becker et al., 2005; Murphy and Topel, 2006; Hall and Jones, 2007; Fleurbaey and Gaulier, 2009; Jones and Klenow, 2016). On the other side, the long-term trend in national health expenditure and its macroeconomic causes and implications have also taken a center stage in recent macroeconomic analyses and policy forums.

In this paper, we focus instead on the joint cyclical behaviors of national health status and health expenditure in their implications for business-cycle studies. Given that life expectancy is often used as a major indicator of national health status and social welfare, following recent macroeconomic literature, we focus on life expectancy as a measure to proxy the latent national health status. In this section, we present empirical evidence on procyclicality of real national health expenditure and countercyclicality of life expectancy. We report here relevant business-cycle moments borne out by data pertaining to US national population. All data used in our empirical analysis are at annual frequency and cover the period 1960-2007.

Data on life expectancy, measured by life expectancy at birth for the population, are from the World Bank World Development Indicators (WDI), while data on total real national health expenditure are from OECD Health Data 2010. Total real health expenditure in a given year is divided by that year's population size to obtain real health expenditure per capita. Data on real GDP and other quantity variables per capita are from the National Income and Product Account (NIPA). We pass the natural logs of all quantity variables through the HP-filter with a smoothing parameter 400 and use variations in detrended GDP as a business-cycle indicator.

Using detrended data, we find the statistical correlation between the cyclical components of life expectancy and real GDP per capita is -0.4041, and that of real national health expenditure and real GDP (both on per-capita basis) is 0.3032, both at 1% statistical significance level. This means that life expectancy is countercyclical although health expenditure is procyclical. The joint cyclical behaviors of these national health variables are the main empirical targets that our macro-health RBC model is aimed to account for. The first column of Table 2 reports various second moments for the variables of interest computed from detrended data, which will be compared against the corresponding moments simulated from our model.

We obtain similar results when raw data are detrended by the BP-filter with a frequency band of 2-8 years. Particularly, the statistical correlation between the cyclical components of life expectancy and real GDP per capita is -0.3929, and that of real national health expenditure and real GDP (both on per-capita basis) is 0.4148, both at 1% statistical significance level. Thus the joint presence of procyclicality of real national health expenditure and countercyclicality of life expectancy is a robust feature of data.

Existing studies support the above conclusion with additional empirical evidence. Complementary to our empirical analysis reported above are studies that cover the Great Depression or the Great Recession, two notable episodes outside our sample. Tapia Granados and Diez Roux (2009) present evidence on countercyclicality of life expectancy in the US for the period 1920-1940. They show that US national health status generally improved during the Great Depression, while life expectancy rose by several years in males, females, whites, and nonwhites, with a countercyclical pattern in the 20 years surrounding the slump. Consistent empirical evidence has also been reported for years surrounding the Great Recession, for the US (e.g., Tapia Granados, 2012; Strumpf et al., 2017) and European countries (e.g., Stuckler et al., 2011; Kristjuhan and Taidre, 2012; Tapia Granados, 2014; Toffolutti and Suhrcke, 2014; Regidor et al., 2014; Tapia Granados and Rodriguez, 2015; Tapia Granados and Ionides, 2017; Ballester et al., 2019). Tapia Granados and Ionides (2016) provide more general and robust empirical evidence on countercyclicality of life expectancy in the US for the period 1948-2013, using various detrending methods and unemployment rate as a business-cycle indicator (see, also, Dehejia and Lleras-Muney, 2004; Ionides et al., 2013). Corroborating general evidence has also been presented for European countries (e.g., Angelini and Mierau, 2014).

While life expectancy at birth as the best comprehensive indicator of population health summarizing age-specific wellness at all ages is increasingly used by the UN, WHO, many other institutions and academic researchers in proxying a nation's general health status, specific health aspects have also been examined in existing studies and the results provide supportive evidence on the countercyclical nature of national health status. For instance, Robinson and Shor (1989) show procyclicality of five types of disabling occupational injuries and acute occupational illnesses, as well as mortality, using data from California for the period 1953-1985. Kossoris (1939) documents the procyclical behavior of disabling industrial injuries in the US for years surrounding the Great Depression, whereby Ruhm (2005b) provides evidence on procyclical morbidity in the US using data from the Behavioral Risk Factor Surveillance System for the period 1987-2000. Likewise, Haaland and Telle (2015) find that other indicators of deteriorated national health status (in addition to mortality rate), such as the rate of becoming disabled, are procyclical, analyzing data from Norway for the period 1977-2008, whereas de la Fuente et al. (2014) present similar evidence for Spain, and Sokejima and Kagamimori (1998) and Liu et al. (2002) for Japan. More generally, treating morbidity (i.e., decline in life quality owing to injuries or diseases) and mortality as attrition from population health stock, Egan et al. (2017) demonstrate that the depreciation of national health capital is procyclical in the US and other industrialized economies over the past half century, confirming the countercyclical nature of national health status.

While morbidity provides a more direct and continuous measure of attrition from health at both individual and aggregate levels, due to greater availability of data on mortality, a larger body of existing studies have focused exclusively on examining crude mortality rates as a rough indicator of attrition from population health. Results from this literature, based on various data types, aggregation levels, econometric specifications, detrending methods, and estimation procedures, generally conform to the countercyclical nature of national health status, manifested by the procyclical nature of general population mortality rate. This conclusion has been reached not only for the US, Canada, European nations, and Japan, but for OECD countries in general, as well as for some middle income economies, and is consistent with the empirical evidence presented in earlier studies.[3]

Empirical evidence on procyclicality of real national health expenditures has also been documented in existing studies, for not only the US but OECD countries in general (e.g., Narayan and Narayan, 2008; Getzen, 2000; Claxton et al., 2013; Lorenzoni et al., 2018). Thus our own analysis and the existing literature provide consistent empirical evidence on the joint presence of procyclical real national health expenditure and countercyclical national health status.

2.2 *Endogenous survival probability and three channels of endogenous health accumulation*

Our model features endogenous survival probability dependent of health history and three channels of endogenous health accumulation described in the introduction.

Endogeneity in survival probability captures a key motive for health investment by allowing health to affect survival prospect and thus life expectancy (e.g., Hall and Jones, 2007; Zhao, 2014; Halliday et al., 2019). This has a direct bearing on the value of statistical life (e.g., Viscusi and Aldy, 2003). Importantly, this builds a link between latent national health stock and observable national health outcome like life expectancy, permitting our model to speak directly with the data.

Additional to enhancing life expectancy, being healthier makes people feel better, bringing them instantaneous satisfaction. This captures Grossman's (1972) notion of a consumption motive for health investment. Furthermore, being healthier also makes consumption and leisure activity more enjoyable, or, health is complementary to consumption and leisure, so better health increases marginal utility of consumption and leisure. This is supported by the findings of Viscusi and Evans (1990), Murphy and Topel (2006), Finkelstein et al. (2013), and Halliday et al. (2019). These motivate our model to include national health stock as a term additional to consumption and leisure in the household's felicity function. While this is the most

[3]See, respectively, Ruhm (2000, 2003, 2005a, 2007), Tapia Granados (2005a), Tapia Granados et al. (2014); Ariizumi and Schirle (2012), Janko et al. (2013); Neumayer (2004), Tapia Granados (2005b), Haaland and Telle (2015), van den Berg et al. (2017); Tapia Granados (2008); Gerdtham and Ruhm (2006); Abdala et al. (2000), Khang et al. (2005), Lin (2009), Gonzalez and Quast (2011); and McAvinchey (1988). Our own empirical analysis based on long US time-series data of death rate and real GDP from WDI and NIPA, and using various detrending methods, conforms to the previous conclusion.

studied channel by the growing macro-health literature for its long-term implications, we here study its implications for the business cycle.

Grossman (1972) also stresses a productivity value of health investment in that a healthier population is more productive. Existing empirical studies lend support to this health-productivity mechanism (e.g., Bloom and Canning, 2000; WHO, 2001; Alleyne and Cohen, 2002; Weil, 2007). These motivate our model to include national health stock as a productive factor along with physical capital and labor in aggregate production function. This modeling approach is also supported by empirical evidence (e.g., Bloom et al., 2004).

While a healthier population is more productive, ample empirical evidence shows that population health deteriorates with aggregate production or general economic activity and this aggregate production-population health depreciation channel is particularly relevant for the business cycle. This was highlighted in Section 2.1 where empirical evidence was quoted on procyclical morbidity and mortality, representing procyclical attrition from population health stock.

A major factor contributing to this mechanism pertains to natural environment. Analyzing over 200 years of data from 32 countries, Cutler et al. (2016) find that the majority of procyclical effects of production on population health deterioration can be attributed to air pollution from carbon dioxide emissions, which are known to be highly procyclical.[4] Focusing on three types of air pollutants, carbon monoxide, particulate matter and ozone, Heutel and Ruhm (2016) reach a similar conclusion. Chay and Greenstone (2003) provide supportive evidence. Corroborating evidence is found in empirical studies that show procyclicality of cause-specific morbidity and mortality like those resultant from respiratory illnesses, cardiovascular and heart conditions or circulatory diseases (e.g., Ruhm, 2000; Miller et al., 2009; Lin, 2009; Toffolutti and Suhrcke, 2014; Heutel and Ruhm, 2016; Sameem and Sylwester, 2017; Tapia Granados and Ionides, 2017), which are known to be sensitive to air pollution.[5]

[4]For instance, Heutel (2012) reaches this conclusion after analyzing US data on GDP and carbon dioxide emissions for the period 1981-2003, where he also finds that electricity generation alone contributes about half of all US carbon dioxide emissions although electric utilities comprise less than 3% of US economy. Tapia Granados et al. (2012) reach a similar conclusion based on data covering a longer period, from 1958 to 2010. Corroborating evidence is also presented by Davis et al. (2010). Such procyclical behavior of pollution, its implications for social welfare, and appropriate policy responses are the central issues studied by a growing macro-environmental science literature that enriches the standard RBC model with pollution externality and government regulation (e.g., Fischer and Springborn, 2011; Heutel, 2012; Fischer and Heutel, 2013; Annicchiarico and Di Dio, 2015; Dissou and Karnizova, 2016; Vasilev, 2018; Gibson and Heutel, 2018).

[5]See, e.g., Dominici et al. (2006). The adverse effects of air (and more generally environmental) pollution on health and life expectancy have long been documented in the environmental and medical science literatures (e.g., Elo and Preston, 1992; Cakmak et al., 1999; Scheffer et al., 2001;

Another factor is related to physical environment. When the economy expands, traffic gets heavier, people connect and interact more often and more closely through increased economic activity, and both common and work places become more crowded. This is also time of increased fatigue and decreased immunity for the working class owing to risen stress of overwork and reduction of sleep time. These spill over into the crowding environment to raise morbidity and mortality of the whole population from traffic accidents and infectious/contagious diseases like influenza/pneumonia (e.g., Kossoris, 1939; Eyer, 1977; Ruhm, 2000; Tapia Granados, 2005; Gerdtham and Ruhm, 2006; Miller et al., 2009; Lin, 2009; Toffolutti and Suhrcke, 2014; French and Gumus, 2014; Cutler et al., 2016; Noland and Zhou, 2017; Sameem and Sylwester, 2017).[6] Similarly, morbidity and mortality resultant from disabling occupational and industrial injuries, acute occupational illnesses, heart and liver diseases, and other unintentional incidents, including those related to the workplaces, are also on the rise (e.g., Catalano, 1979; Catalano and Serxner, 1987; Robinson and Shor, 1989; Karasek and Theorell, 1990; Sparks et al., 1997; Sokejima and Kagamimori, 1998; Ruhm, 2000; Liu et al., 2002; Tapia Granados, 2005; Gerdtham and Ruhm, 2006; Boone and van Ours, 2006; Davies et al., 2009; Toffolutti and Suhrcke, 2014; Fuente et al., 2014; Haaland and Telle, 2015; Cutler et al., 2016).[7]

A third factor emphasized by existing empirical studies has to do with procyclical unhealthy behaviors like alcohol\tobacco use, unhealthy diet, and sedentary lifestyle (e.g., Ruhm, 2000, 2003, 2005b; Ruhm and Black, 2002; Deaton and Paxson, 2004; Dehejia and Lleras-Muney, 2004; Tapia Granados, 2005; Snyder and Evans, 2006; Asgeirsdottir et al., 2012; Xu, 2013; Cutler et al., 2016).

These three factors motivate an endogenous component modeled into the depreciation rate of population health that increases with aggregation production.

The health economics literature has long documented that not only medical care but leisure can be important for maintaining health.[8] Evidence on the contribution of leisure to health is also found in biomedical science, public health, psychobiology, and biosociology literatures, based on clinical, experimental, and survey studies. Many such studies discover specific health benefits of individual leisure activities, while

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Evans and Smith, 2005; Jouvet et al., 2007; Mariani et al., 2010).

[6] See, also, Marmot (2004), Marmotet al. (2008), and Entringer et al. (2008) for related evidence on the spill-over effects.

[7] Our own empirical work based on various detrending methods and data on work-related injuries produced by the US Bureau of Labor Statistics Census of Fatal Occupational Injuries for the period 1992-2010 shows procyclicality of total work-related injuries and each major category.

[8] See Grossman (1972), Gronau (1977), Kenkel (1995), Sickles and Yazbeck (1998), Ruhm (2000), Contoyannis and Jones (2004), and Insler (2011). He and Huang (2013) and He et al. (2013) provide a comprehensive review of the evidence.

some studies find reduced medical expenditure from increased leisure time.[9] Pressman et al. (2009) establish a general link between a wide array of leisure activities[10] and a broad variety of health benefits.[11] Caldwell (2005), Russell (2009), and Payne et al. (2010) provide a comprehensive review of empirical evidence on the importance of leisure for maintaining health, and an intuitive account of the prevention, coping, and transcendence mechanisms by which leisure enhances physical, mental, social, and cognitive health.[12] Econometric estimations of health production function based on structural models, with both medical commodity and leisure time as inputs, have been obtained by Sickles and Yazbeck (1998) using US time-series data, and by He et al. (2013) using panel data for 35 countries from the OECD, the World Bank, and the Conference Board. These studies confirm that both medical care and leisure contribute to maintaining health, with some elasticity of substitution between the two inputs in health production.

Importantly, as suggested by a large body of this empirical literature, many health benefits (e.g., better social networks and supports, better feelings of satisfaction or engagement in lives, lower stress or depression levels) generated by leisure-time activities (e.g., socializing, visiting friends or family, going to clubs or religious events) not only accrue to selves, but spill over to others.[13]

Also relevant for our paper, many empirical studies suggest particular importance of the cyclical allocation of time pertaining to health maintenance (e.g., Mitchell, 1951; Biddle and Hamermesh, 1990; Ruhm, 2000, 2005b; Tapia Granados, 2005; Asgeirsdottir et al., 2012; Dave, 2016). A key finding from this literature is also that, even at the business-cycle frequency, major health benefits associated with time made available from reduced market work come from spillover effects (e.g., Miller et al., 2009; Bezruchka, 2009; Tapia Granados et al., 2014). Special attention is paid to intra-household spillovers. Dehejia and Lleras-Muney (2004), Ruhm (2007), and Roth et al. (2013) show how salutary activities made available from reduced work

[9] For example, leisurely walking or cycling, exercising, vacationing, spending time in nature, engaging in social activities, having hobbies, sleeping and restorative activities have all been shown to improve physical, mental, social, or cognitive health, while help reducing medical expenditure. See He and Huang (2013) for an extensive list of references.

[10] Such leisure activities include socializing, visiting friends or family, going on vacation or to clubs or religious events, having hobbies, playing sports, and spending time unwinding or in nature.

[11] Examples of such health benefits are better social networks and supports, feelings of satisfaction or engagement in lives, physical function or mood, and sleep; and lower stress or depression levels, cortisol measurements, blood pressure, body mass index, and waist circumference.

[12] See He and Huang (2013) for an extensive list of additional references.

[13] See, also, Berkman and Glass (2000) and Ruhm (2003, 2005a&b, 2007), who show that having friends, socializing, or spending time with family enhances the longevity and health of not only selves but also friends, other encounters, or family members especially children.

time can benefit the health of not only selves, but children, other family members or relatives. Coleman and Dave (2013) and Dave (2016) emphasize spillovers across married or cohabiting couples. They find that reduced time at work for one spouse not only makes self more time available for salutary activities, but through taking on joint household responsibilities also frees up the other spouse's time which then is spent on personal care, socializing and relaxing, exercising and sleeping, all of which enhance physical, mental, social, and cognitive health.[14] Through the socioeconomic and contextual networks, individuals' own time allocations over the business cycle affect not only their own health wellbeing, but national health status.

These together suggest a role, given that time away from market work fluctuates countercyclically, of the time channel in generating countercyclical national health status in the face of procyclical real national health expenditure.

More direct evidence on countercyclicality of time allocated to maintaining health is found from the BLS American Time Use Survey (ATUS). Applying Tobit regression to pooled data observed at monthly frequency from ATUS 2003-2009, and using state-level labor market conditions as a business-cycle indicator, Edwards (2011) finds that, while labor time falls in economic downturns, time spent sleeping, eating, telephoning, traveling, and especially socializing and relaxing, all increase significantly. Aguiar et al. (2013) report that about 50% of the foregone labor time during the Great Recession was relocated to sleeping and exercising, etc., and 5% to self-caring. These studies focus on individuals' own time allocations across the business cycle. Coleman and Dave (2013) obtain consistent evidence based on data from ATUS 2003-2010, but they emphasize the importance of spillover effects working through the socioeconomic and contextual networks. These together provide coherent evidence on countercyclical allocation of time to health maintenance.

Taken together, these motivate our model to incorporate a health production function with both medical care and leisure as inputs.

3 Model

An agent has a probability $\pi(h^t)$ to survive through period t conditional on his health history $h^t \equiv (h_0, h_1, ...h_t)$, which satisfies the Markov property so the probability

[14] This can also lead to healthier family relationships. One piece of indicative evidence is presented by Hellerstein and Morrill (2011), who discover that divorce rate is significantly procyclical after analyzing US state-level data for the period 1976-2009. They show that the result is robust to a host of alternative empirical specifications, to disaggregating by state characteristics and time period, to using alternative business-cycle indicators, and to expanding the data series back to 1970. Hellerstein et al. (2013) conduct additional robustness checks and reach the same conclusion.

of surviving through t conditional on having survived through $t-1$, denoted as $\Psi(h_t) \equiv \pi(h_t|h^{t-1})$, depends only and monotonically on his date-t health stock h_t.

The agent's period-t utility $U(c_t, l_t, h_t)$ depends on consumption c_t, leisure l_t, and health stock h_t (utility channel).

Period-t output $y_t = F(k_t, n_t, h_t; z_t)$ depends on total factor productivity z_t, physical capital k_t, labor n_t, and health capital h_t (productivity channel).

Health stock depreciates with output according to $\Delta(y_t)$ (depreciation channel). Health investment is created using medical commodity m_t and leisure l_t according to $H(m_t, l_t)$ (time channel).

The productivity and depreciation channels are collectively referred as production channel. The felicity, production and depreciation functions U, F, H and Δ satisfy the usual properties.

The model is closed with a law of motion for physical capital, $k_{t+1} = (1-\delta_k)k_t + i_t$ where δ_k is physical capital depreciation rate and i_t is physical capital investment, a law of motion for health capital, $h_{t+1} = [1-\Delta(y_t)]h_t + H(m_t, l_t)$, a resource constraint for goods, $c_t + i_t + m_t = y_t$, a time constraint, $l_t + n_t = 1$, and a stochastic driving process for TFP as shown in (6).

The representative agent solves the following problem:

$$\max \quad \mathrm{E}\sum_{t=0}^{\infty} \beta^t \pi(h^t) U(c_t, l_t, h_t) \tag{1}$$

$$\text{s.t.}$$

$$\begin{aligned}
c_t + i_t + m_t &= F(k_t, n_t, h_t; z_t) && (2)\\
h_{t+1} &= [1-\Delta(y_t)]h_t + H(m_t, l_t) && (3)\\
k_{t+1} &= (1-\delta_k)k_t + i_t && (4)\\
l_t + n_t &= 1 && (5)\\
\ln z_t &= (1-\rho_z)\ln z + \rho_z \ln z_{t-1} + \epsilon_t, \ \ \epsilon_t \sim \mathrm{N}(0, \sigma_\epsilon) && (6)\\
c_t, i_t, m_t, l_t, n_t, k_{t+1}, h_{t+1} &\geq 0, \ \ k_0, h_0 \text{ given}
\end{aligned}$$

where E is the expectations operator and β is a discount factor.

The first order conditions for optimal intertemporal allocation of consumption and accumulation in physical capital imply

$$U_c(t) = \beta \mathrm{E_t}\Psi(h_{t+1})U_c(t+1)\left[F_k(t+1) + 1 - \delta_k - \frac{\Delta_y(t+1)F_k(t+1)h_{t+1}}{H_m(t+1)}\right] \tag{7}$$

where $F_k \equiv \partial F/\partial k$, $\Delta_y \equiv \partial\Delta(y)/\partial y$, and $H_m \equiv \partial H/\partial m$. The condition equates the utility cost of giving up one unit of consumption with the present value of expected future benefit from investing the foregone consumption in physical capital.

The first order conditions for consumption, leisure and medical commodity imply

$$F_n(t) = \frac{U_l(t)}{U_c(t)} + \frac{\Delta_y(t)F_n(t)h_t}{H_m(t)} + \frac{H_l(t)}{H_m(t)} \tag{8}$$

which equates the cost of leisure with the benefit of additional leisure including saved consumption while maintaining utility, and saved medical commodity while maintaining health stock by retaining existing health capital and by creating new health investment.

Combining the first order conditions for optimal accumulation in health capital and intratemporal allocation between consumption and medical commodity yields

$$\begin{aligned}\frac{U_c(t)}{H_m(t)} &= \beta \mathrm{E_t} \Psi(h_{t+1}) \\ &\left\{ \begin{array}{c} U_h(t+1) + U_c(t+1)F_h(t+1) + \frac{\Psi'(h_{t+1})}{\Psi(h_{t+1})}U(t+1) \\ +[1-\Delta(y_t) - \Delta_y(t+1)F_h(t+1)h_{t+1}]\frac{U_c(t+1)}{H_m(t+1)} \end{array} \right\}\end{aligned} \tag{9}$$

which equates the foregone marginal utility from relocating consumption to medical commodity for health investment with the present value of expected future benefit from additional health capital. The future benefit is, additional to enhanced survival prospect, captured by the four terms inside the bracket on the right side of (9), including marginal utilities from additional health capital directly and from additional consumption made available by increased output brought about by additional health capital, salvaged utility due to extended life span generated from additional health capital, and savings on future health investment.

We parameterize preferences and technologies with the following functional forms:

$$\Psi(h_t) = 1 - \frac{1}{e^{\kappa h_t}} \tag{10}$$

$$U(c_t, l_t, h_t) = \ln\left(\left[\lambda c_t^{1-\eta} + (1-\lambda)h_t^{1-\eta}\right]^{\frac{1}{1-\eta}} - \phi\frac{(1-l_t)^{1+\chi}}{1+\chi} \right) + b \tag{11}$$

$$F(k_t, n_t, h_t; z_t) = z_t k_t^{\alpha}(n_t h_t)^{1-\alpha} \tag{12}$$

$$\Delta(y_t) = \delta_h + \frac{y_t^{\varpi}}{\varpi} \tag{13}$$

$$H(m_t, l_t) = \begin{cases} B[\theta m_t^{\frac{\omega-1}{\omega}} + (1-\theta)l_t^{\frac{\omega-1}{\omega}}]^{\frac{\omega\xi}{\omega-1}} & \text{if } \omega \neq 1 \\ B(m_t^{\theta} l_t^{1-\theta})^{\xi} & \text{if } \omega = 1. \end{cases} \tag{14}$$

The survival probability (10) takes the same parametric form as in Zhao (2014), implying a life expectancy of $e^{\kappa h_t}$ at date t. Function (11) parameterizes preferences à là Greenwood et al. (1988). The endogenous component of (13) captures various impacts of economic activity on population health depreciation summarized in Section 2.2. The creation of health investment (14) is parameterized in light of Sickles and Yazbeck (1998) and He et al. (2013).

We set $\kappa = 22.9450$, so the model implies a long-run average life expectancy of 73.86 years, as observed for the US over the period 1960-2007.

We set $\beta = 0.9709$ (annual) to match a long-run physical capital-output ratio of 3.32. We choose α and δ_k to ensure a share of payment to physical capital of 0.4 and an annual physical capital depreciation rate of 0.076.

These imply an investment-output ratio of 25% and a total consumption-output ratio of 75%, in line with NIPA (1960-2007). The average US medical expenditure-output ratio for the same period computed from OECD Health Data 2010 is 10.2%, thus the ratio of consumption (excluding medical commodity) to output is 64.8%. This implies $\lambda = 0.5575$. We set $\eta = 8.85$, consistent with Viscusi and Evans (1990), Murphy and Topel (2006), Finkelstein et al. (2013) and Halliday et al. (2019). Some studies assume smaller values for η (e.g., Jung and Tran, 2016; Yogo, 2016). Our results are robust to these alternative choices of η. We set $\phi = 2.1321$ so that labor takes up about one-third of discretionary time (average 0.318 for 1960-2007). We set $\chi = 2$ as is standard in the business-cycle literature.

The term b in (11) is chosen to ensure positivity of period utility so that it is worthy to enhance life expectancy. It has a direct bearing on the value of statistical life (VSL), which in our model corresponds to the marginal cost of saving a life measured by $\text{VSL} = [\partial\Psi(h)/\partial m]^{-1}$. Substituting this measure into the steady-state versions of (7)-(9) yields a relationship between b and the steady-state value of VSL. We set $b = 8.1$ to match this steady-state VSL in our model with the mean VSL observed from the data (6.3 million USD) reported by the US Food and Nutrition Service (USDA) and Environmental Protection Agency (EPA).[15] We verify that with this value of b the flow utility remains positive in all of our model simulations.

The biology literature on natural aging of human body documents that as humans age they develop an increasing number of disorders called "deficits". Dalgaard and Strulik (2010) show that the average individual accumulates about 4% more deficits per year using data from four developed countries including the US. We set natural health capital depreciation rate $\delta_h = 4\%$. We set $\varpi = 4$ implying a production-related health capital depreciation rate of 0.0077% per year in the steady state. Our

[15] See, also, Table 12 in Viscusi and Aldy (2003) and Table 1 in Hall and Jones (2007). Jones and Klenow (2016) calibrate b to match a very similar target of VSL.

results are robust to alternative values of these two parameters.

We set $\omega = 1$ in light of the empirical estimates by Sickles and Yazbeck (1998) and He et al. (2013). We set $B = 0.0331$ and $\theta = 0.2793$, to be consistent with the average shares of real GDP (10.2%) and of total private consumption expenditure (12.4%) that are devoted to medical goods and services in the US during the period 1960-2007, computed from NIPA and OECD Health Data 2010. We set $\xi = 1$ following Grossman (1972) and much of the macro-health literature. Our results are robust when we lower ξ to 0.5, a value suggested by Ehrlich and Chuma (1990).

We normalize z to 1 and set ρ_z to 0.95. We estimate σ_ϵ as 0.0173 using annual NIPA data for the period 1960-2007.

Table 1 summarizes these parameter values.

4 Results

Table 2 reports correlations with and standard deviations relative to GDP for five variables of interest, including consumption (exclusive of health care), investment, labor input, health care, and life expectancy, computed from data (first column), model (second column), and ten variants of model in which one or more channels of endogenous health accumulation are shut off (third to twelfth columns). While the statistics for US economy are computed from the HP-filtered data covering the period 1960-2007 as described in Section 2.1, the statistics for the model are computed from the artificial time series which are averages over 200 simulations of 150 periods each.

Comparing the first two columns of the table shows that the model does a good job in explaining the cyclical behaviors of the two national health variables: one on input (national health expenditure), the other on output (life expectancy). The model accounts for 89% of the observed standard deviation of national health expenditure relative to that of GDP (0.721 in the model versus 0.812 in the data), and 49% of the observed standard deviation of life expectancy to that of GDP (0.065 in the model versus 0.134 in the data). Importantly, the model produces procyclical national health expenditure and countercyclical life expectancy. In fact, the match in the degree of cyclicality of life expectancy is near perfect (-0.3951 in the model versus -0.4041 in the data), though correlation between national health expenditure and GDP is higher in the model than seen from the data.[16]

Our model does a similar job as the standard RBC model in explaining the cyclical

[16] Incorporating uninsurable idiosyncratic health shocks or/and shocks to medical technology should help bring the degree of procyclicality in national health expenditure generated from the model closer to observed in the data.

behaviors of traditional macroeconomic variables with marginal improvements in matching the volatilities of consumption and output.

To decompose the individual contributions of various channels of endogenous health accumulation and quantify the roles of their interactions in generating the above results, we examine ten variants to our baseline model:[17]

With only utility channel (uti)
Replace h_t by 1 in (12), take out y_t^{ϖ}/ϖ from (13), and set $\theta = 1$ in (14).

With only production channel (pro)
Set $\lambda = 1$ in (11) and $\theta = 1$ in (14).

With only depreciation channel (dep)
Set $\lambda = 1$ in (11) and $\theta = 1$ in (14), and replace h_t by 1 in (12).

With only productivity channel (pdt)
Set $\lambda = 1$ in (11) and $\theta = 1$ in (14), and take out y_t^{ϖ}/ϖ from (13).

With only time channel (time)
Set $\lambda = 1$ in (11), replace h_t by 1 in (12), and take out y_t^{ϖ}/ϖ from (13).

No time channel (no time)
Set $\theta = 1$ in (14).

No production channel (no pro)
Replace h_t by 1 in (12) and take out y_t^{ϖ}/ϖ from (13).

No depreciation channel (no dep)
Take out y_t^{ϖ}/ϖ from (13).

No productivity channel (no pdt)
Replace h_t by 1 in (12).

No utility channel (no uti)
Set $\lambda = 1$ in (11).

The third to twelfth columns of Table 2 report structural decomposition results obtained from simulating these variants. Comparing these columns against the first

[17]In each variant, certain parameters are recalibrated to match relevant steady-state conditions with corresponding moment conditions for US economy. Particularly, the unconditional mean of TFP is adjusted to ensure that the steady-state behavior of each variant remains consistent with the long-run average behavior of US economy not only in relevant ratios but also in levels. The details of recalibrations are not reported here but are available upon request from the authors. Our decomposition results do not change significantly when we do not recalibrate.

and second shows that each individual channel of endogenous health accumulation works in the right direction in explaining the cyclical behaviors of national health expenditure and life expectancy, and interactions among these channels also play roles in shaping the model's quantitative fit with the data.

To put this in perspective, our baseline model with all channels operative produces a near-perfect match with key empirical target, countercyclical correlation of life expectancy with GDP. Turning off some channel(s) generates deviations from this match - sometimes to a great degree, and other times more modestly - although in no case they alter the sign of correlation into a wrong direction. As for explaining procyclical correlation of national health expenditure with GDP, both the baseline model and its variants markedly overshoot the empirical target, reflecting primarily the fact that our setting is fairly stylized in the tradition of the standard RBC literature with just a TFP shock.

In matching the standard deviation of national health expenditure relative to that of GDP, the performance improves - but only marginally - in three variants, and deteriorates in seven - either moderately, or more dramatically. As for matching the standard deviation of life expectancy relative to that of GDP, the performance improves - either very marginally, or more appreciably - in five variants, and deteriorates in the other five - either slightly, or more notably.

Finally, all variants perform similarly as the baseline model in matching other moments of the data concerning the cyclical behaviors of traditional macroeconomic variables.

We have done extensive sensitivity analyses and found our main conclusions hold quite robustly (the main results from these sensitivity analyses are reported in the appendix and summarized in Tables A.1 and A.2 which are attached to the end of this paper). All in all, the data seem to favor our baseline model over all of its variants. The structural decomposition results suggest some roles for interactions among all channels of endogenous health accumulation in helping improve the model's quantitative fit with the observables. This is so even though the individual channels when standing alone by themselves, or working together by any proper subsets, already move to the right direction in explaining the data.

5 Conclusion

The model developed in this paper is admittedly stylized in the tradition of standard RBC literature. Yet we view it as a necessary first step in building more sophisticated macro-health models of the business cycle. Our simple model is already successful in getting in line with salient empirical regularities that a satisfactory macro-health business-cycle model should account for. It is also rich enough to yield important lessons about the various channels of endogenous health accumulation documented in multiple scientific disciplines, as they pertain to the cyclical behaviors of national health and traditional macroeconomic variables. Viewed from this perspective, we take the framework presented here as a springboard for future macro-health business-cycle research that needs to take into account more frictions and shocks.

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Table 1: Parameter values

Parameters		Values
	Survival Motive	
κ	curvature parameter in survival probability function	22.9450
b	constant term in period utility function	8.10
	Utility	
β	subjective discount factor	0.9709
λ	share of consumption in consumption-health bundle	0.5575
η	inverse elasticity of substitution between consumption and health	8.85
ϕ	weight of leisure	2.1321
χ	inverse of Frisch labor supply elasticity	2
	Production	
α	share of physical capital in value-added inputs	0.4
δ_k	depreciation rate of physical capital	0.076
z	unconditional mean of TFP	1
ρ_z	autoregressive coefficient in log TFP process	0.95
σ_ε	standard deviation of innovation in log TFP process	0.0173
	Health Accumulation	
δ_h	natural depreciation rate of health capital	0.04
ϖ	curvature parameter in production related health depreciation rate	4
θ	share of medical commodity in health investment	0.2793
ω	elasticity of substitution between health care and leisure	1
B	technology level for health production	0.0331
ξ	returns to scale in health production	1

Table 2: Data[a] against baseline model and its variants[b]

			Variants									
Statistics	Data	Model	uti	pro	dep	pdt	time	no time	no pro	no dep	no pdt	no uti
Correlations with GDP												
Consumption	0.93	0.97	0.98	0.97	0.98	0.97	0.98	0.97	0.98	0.97	0.98	0.97
Investment	0.89	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Labor	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Health care	0.30	0.96	0.86	0.97	0.87	0.97	0.85	0.97	0.85	0.96	0.87	0.85
Life expectancy	-0.40	-0.40	-0.34	-0.23	-0.34	-0.22	-0.57	-0.23	-0.54	-0.39	-0.57	-0.42
Standard deviations relative to GDP												
Consumption	0.81	0.62	0.65	0.62	0.66	0.61	0.65	0.61	0.65	0.62	0.65	0.62
Investment	2.33	2.18	2.21	2.16	2.19	2.19	2.23	2.16	2.23	2.21	2.20	2.19
Labor	0.79	0.31	0.33	0.33	0.33	0.33	0.34	0.33	0.34	0.32	0.33	0.32
Health care	0.81	0.72	0.47	0.76	0.49	0.76	0.51	0.76	0.51	0.71	0.53	0.69
Life expectancy	0.13	0.07	0.08	0.11	0.08	0.11	0.05	0.12	0.06	0.07	0.05	0.06

[a]The statistics are computed from the HP-filtered (with a value of 400 for the smoothing parameter) annual data for US economy covering the period 1960-2007. Data Sources: OECD 2010 (national health expenditure); WDI (life expectancy); NIPA (GDP, consumption, investment, labor).

[b]The statistics for the baseline model and each of its variants are computed from the simulated time series which are averages over 200 simulations of 150 periods each.

A. Appendix (not intended for publication)

We conduct here sensitivity analyses to check the robustness of our main conclusions.

A.1 CRRA preferences

Our first check pertains to the robustness of results to the presence of wealth effect on labor supply that is eliminated by GHH preferences so as to amplify the volatility of labor input, one dimension of the data on which the standard RBC model with CRRA preferences falls significantly short of fitting.

For this sensitivity analysis, we hence replace the GHH utility function in (11) with the CRRA utility function below:

$$U(c_t, l_t, h_t) = \frac{\ln\left(\lambda c_t^{1-\eta} + (1-\lambda) h_t^{1-\eta}\right)}{1-\eta} - \phi \frac{(1-l_t)^{1+\chi}}{1+\chi} + b. \tag{15}$$

We then re-solve the model and all of its variants following the same procedure as in Section 4, with proper re-calibrations (see Footnote 17). Table A.1 reports the results.

Examining Table A.1 in the same way as we did above to Table 2 and comparing the results across the two tables lead to the following two observations.

First, the consequence of eliminating the wealth effect on labor supply in modeling lies mainly in much amplified volatility of labor input, and to some lesser extents of consumption too but moderated volatility of investment, both relative to that of output and in absolute values (not reported in the tables), as well as (also to some lesser extent) increased volatility of output itself (also not reported in the tables), in our enriched settings with all or some of the channels of endogenous health accumulation, just as is well known in the standard RBC setting that abstracts from all health measures. These all help to move the model closer to the data in terms of the traditional business-cycle moments. The presence of the various channels of endogenous health accumulation, or lack thereof, does not change this conclusion.

Second, and more important for the purpose of this paper, the roles of the various channels of endogenous health accumulation and their interactions in accounting for the joint cyclical behaviors of national health variables, as well as in matching the traditional business-cycle moments are robust to inclusion or not in modeling of the wealth effect on labor supply. All in all, the data still seem to favor our baseline model with all of the channels of endogenous health accumulation operative over any of its variants even with CRRA preferences, just as with GHH preferences.

A.2 Unhealthy consumption

Our second robustness check impinges in modeling an additional factor of endogenous health accumulation that may affect health depreciation and utility simultaneously. As documented in Section 2, unhealthy behaviors like alcohol and tobacco use or unhealthy diet show a procyclical pattern. Whereas such consumption may generate instantaneous satisfaction, it is harmful to health. We are interested in seeing how the presence of these conflicting effects may affect our main results.

For this sensitivity analysis, we thus replace the period utility function in (11) by

$$U(c_{g,t}, c_{b,t}, l_t, h_t) = \ln\left(\left[\lambda c_{g,t}^{1-\eta} + (1-\lambda) h_t^{1-\eta}\right]^{\frac{1}{1-\eta}} - \phi\frac{(1-l_t)^{1+\chi}}{1+\chi}\right) + \upsilon \ln(c_{b,t}) + b, \tag{16}$$

for some $\nu > 0$, where $c_{g,t}$ and $c_{b,t}$ denote health neutral and harmful consumption, respectively, while to capture the health depreciation effect of 'bad' consumption, we replace the health capital depreciation function in (13) with

$$\Delta(y_t, c_{b,t}) = \delta_h + \frac{y_t^{\varpi}}{\varpi} + \frac{c_{b,t}^{\zeta}}{\zeta}, \tag{17}$$

for some $\zeta > 0$, with the sum of $c_{g,t}$ and $c_{b,t}$ giving rise to the total consumption c_t (excluding health care). Other features of the model remain the same as in baseline.

The way of modeling health harmful consumption in (16)-(17) above introduce two additional parameters, υ and ζ. Recall in Section 3 we have available seven moment conditions from the data that are used to calibrate the seven parameters, β, κ, λ, ϕ, θ, B, and b in the baseline model. In the current context one additional piece of information from the data, the share of alcohol and tobacco consumption as a fraction of total nondurable goods expenditure, becomes relevant. This share of health harmful consumption computed from NIPA averages about 9.1% over the period 1995-2007. Since the value of β is fairly stable across variants of the baseline model examined before, we fix it to its baseline value reported in Table 1, which is also close to values typically used in the standard business-cycle literature. This leaves us with eight parameters to match eight moment conditions. Comparable results are obtained when the unconditional mean of TFP is recalibrated along with these eight parameters so that the steady-state behavior of the model remains consistent with the long-run average behavior of US economy not only in relevant ratios but in levels as well (see Footnote 17).

We find that enriching the baseline setting with unhealthy consumption improves the model's fit on the national health variables. The simulated standard deviations of national health expenditure and life expectancy relative to that of GDP both increase, from 0.72 and 0.07 in the baseline setting, to 0.81 and 0.12 here, which are much closer to the data for which the two statistics are 0.81 and 0.13, respectively. The fit on the countercyclical correlation between life expectancy and GDP also improves, though only marginally, from -0.3951 in the baseline setting, to -0.4003 here, slightly closer to the observed value -0.4041. The fit of this enriched model on the other business-cycle moments remains similar as in the baseline framework.

To check the robustness of this conclusion, we also conduct this sensitivity analysis under an alternative specification of the period utility function,

$$U(c_{g,t}, c_{b,t}, l_t, h_t) = \ln\left(\left[\lambda c_{g,t}^{1-\eta} + (1-\lambda) h_t^{1-\eta}\right]^{\frac{1}{1-\eta}} + \upsilon c_{b,t} - \phi \frac{(1-l_t)^{1+\chi}}{1+\chi}\right) + b, \quad (18)$$

which bundles health harmful consumption with health neutral consumption, health stock, and leisure into a GHH form, under which the marginal utility of unhealthy consumption is decreasing with health status, rather than treating it as an additively separable term as in (16), under which the marginal utility of unhealthy consumption is independent of health status.

The simulated cyclical moments for all variables, except for consumption, are similar with (18) as with (16), and they remain reasonably close to observables. That said, the consumption data seem to favor (16) over (18). Under (18), health neutral consumption is significantly countercyclical, with a correlation with GDP of -0.41, and excessively smooth, with a standard deviation relative to GDP of merely 0.01, while health harmful consumption is excessively volatile, with a standard deviation relative to GDP of 6.80, totally at odds with empirical observations. In contrast, as reported above, the consumption moments under (16) are much more reasonably looking and closer to the data.

Thus one takeaway from the exercises in this section is that, while enriching the baseline framework with unhealthy consumption may generally improve the model's fit to the data, the consumption data seem to favor a version of the enriched setting in which the marginal utility of health harmful consumption is independent of health status over one in which it is decreasing with health status.

A.3 Alternative parameter values

Our main results are obtained with most parameters calibrated to match the model implied first-moment conditions with the long-run historical averages of observables, but with the values of a few parameters borrowed from the existing literature. We want to see how sensitive our results are to alternative values of these parameters.

We begin with the curvature parameter governing the production related health depreciation rate, which is set at $\varpi = 4$ in the baseline, implying a production related depreciation in health stock of 0.0077% per year in the steady state. We consider here two alternative values for this parameter, $\varpi = 3$ and $\varpi = 5$, implying a production related depreciation in health stock of 0.077% and 0.0008% per year in the steady state, respectively. These two alternatives give rise to a wide range of health depreciation related to steady-state economic activity, with the former being ten times and the latter about only one tenth of the baseline value. Variations in ϖ within this range have very modestly effects on results, as can be seen by comparing the second and third columns against the first in Table A.2.

We then go to the parameter governing the natural rate of health depreciation, which is set at $\delta_h = 4\%$ in the baseline. We also consider here two alternative values for this parameter, 3% and 5%, respectively. Once again, variations in δ_h within this range have fairly marginal effects on results, as can be seen by comparing the fourth and fifth columns against the first in Table A.2.

We go next to the inverse elasticity of substitution of consumption and health in preferences, which is set at $\eta = 8.85$ in the baseline, implying a high degree of complementarity between the two, as is consistent with a large body of empirical literature. We consider here an alternative value for this parameter, $\eta = 1$, which corresponds to the standard Cobb-Douglas specification, making consumption and health fairly substitutable. Even such a large swing in η has only moderate effects on results, as is seen by comparing the sixth column against the first in Table A.2.

Finally, we check the parameter governing returns to scale in health production, which is set at $\xi = 1$ in the baseline, corresponding to constant returns to scale. We here consider the case with $\xi = 0.5$, to allow for a significant degree of decreasing returns to scale in health production. Even such a large swing in ξ generates very minor effects on all cyclical moments, except the correlation between life expectancy and GDP, for which the effect is relatively more significant. This can be seen by comparing the last column against the first in Table A.2.

We have done additional robustness checks and found that our basic results hold quite generally. In general, these changes in model features or parameter values can have some effects - sometimes very modestly, and other times to a greater degree - but in no case they alter the main conclusions. Overall, the model does a good job in accounting for the cyclical behaviors of national health and other macroeconomic variables. The various channels of endogenous health accumulation all work to the right direction in matching observables, and their interactions also play a role in helping improve the model's quantitative fit with the data.

Table A.1: Data[a] against model with CRRA preferences and its variants[b]

			Variants									
Statistics	Data	Model	uti	pro	dep	pdt	time	no time	no pro	no dep	no pdt	no uti
Correlations with GDP												
Consumption	0.93	0.93	0.93	0.93	0.93	0.92	0.93	0.93	0.93	0.92	0.94	0.93
Investment	0.89	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Labor	0.80	0.91	0.92	0.93	0.92	0.93	0.92	0.93	0.92	0.91	0.91	0.91
Health care	0.30	0.96	0.91	0.97	0.91	0.97	0.86	0.97	0.86	0.96	0.87	0.95
Life expectancy	-0.40	-0.37	-0.30	-0.22	-0.30	-0.22	-0.48	-0.22	-0.47	-0.36	-0.48	-0.38
Standard deviations relative to GDP												
Consumption	0.81	0.53	0.56	0.53	0.56	0.52	0.56	0.53	0.56	0.53	0.56	0.54
Investment	2.33	2.48	2.52	2.46	2.51	2.48	2.53	2.45	2.53	2.50	2.51	2.48
Labor	0.79	0.09	0.09	0.08	0.17	0.09	0.09	0.08	0.09	0.09	0.09	0.09
Health care	0.81	0.76	0.54	0.80	0.56	0.80	0.53	0.81	0.53	0.76	0.54	0.74
Life expectancy	0.13	0.10	0.09	0.12	0.09	0.12	0.08	0.12	0.08	0.11	0.08	0.10

[a] The statistics are computed from the HP-filtered (with a value of 400 for the smoothing parameter) annual data for US economy covering the period 1960-2007. Data Sources: OECD 2010 (national health expenditure); WDI (life expectancy); NIPA (GDP, consumption, investment, labor).

[b] The statistics for the model with CRRA preferences and each of its variants are computed from the simulated time series which are averages over 200 simulations of 150 periods each.

Table A.2: Model with baseline or alternative parameter values[a]

Statistics	Baseline	$\varpi = 3$	$\varpi = 5$	$\delta_h = 0.03$	$\delta_h = 0.05$	$\eta = 1$	$\xi = 0.5$
Correlations with GDP							
Consumption	0.97	0.98	0.97	0.97	0.97	0.96	0.97
Investment	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Labor	1.00	1.00	1.00	1.00	1.00	0.99	1.00
Health care	0.96	0.97	0.96	0.96	0.96	0.95	0.97
Life expectancy	-0.40	-0.48	-0.40	-0.36	-0.50	-0.47	-0.26
Standard deviations relative to GDP							
Consumption	0.62	0.65	0.62	0.61	0.63	0.60	0.62
Investment	2.18	2.08	2.20	2.18	2.18	2.27	2.17
Labor	0.31	0.28	0.32	0.31	0.31	0.27	0.33
Health care	0.72	0.76	0.70	0.78	0.68	0.69	0.74
Life expectancy	0.07	0.05	0.06	0.08	0.05	0.05	0.09

[a]The statistics for each case of the model under either the baseline or the alternative parameter values are computed from the simulated time series which are averages over 200 simulations of 150 periods each.