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Real business cycle with endogenous health

Kevin x.d. Huang
Vanderbilt University

Hui He
Shanghai University of Finance and Economics

Sheng-ti Hung
University of Hawaii at Manoa

Abstract

A macro-health model with endogenous survival probability dependent on health history builds in an RBC framework three channels of endogenous health accumulation documented in several scientific disciplines: (1) health affects utility; (2) health affects productivity but depreciates with labor or production; and (3) health is maintained with medical care or leisure activity. The model generates pro-cyclical healthcare and mortality, in line with data, and other aggregate properties seen in the RBC literature. We find that (2) and (3) are key to explaining the cyclical behaviors of health variables while broader features of data also favor a model without (1).

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Contact: Kevin x.d. Huang - kevin.huang@vanderbilt.edu, Hui He - he.hui@mail.shufe.edu.cn, Sheng-ti Hung - shengti@hawaii.edu.
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Real Business Cycle with Endogenous Health*

Hui He† Kevin X.D. Huang‡ Sheng-Ti Hung§

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A macro-health model with endogenous survival probability dependent on health history builds in an RBC framework three channels of endogenous health accumulation documented in several scientific disciplines: (1) health affects utility; (2) health affects productivity but depreciates with labor or production; and (3) health is maintained with medical care or leisure activity. The model generates pro-cyclical healthcare and mortality, in line with data, and other aggregate properties seen in the RBC literature. We find that (2) and (3) are key to explaining the cyclical behaviors of health variables while broader features of data also favor a model without (1).

JEL classification: E22, E32, I12

Keywords: Macro-health; Business cycle; Mortality; Health expenditure; Time allocation

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†School of Economics, the Shanghai University of Finance and Economics, Shanghai, China 200433; e-mail: he.hui@mail.shufe.edu.cn. International Monetary Fund; e-mail: HHe@imf.org.

‡Department of Economics, Vanderbilt University, 2301 Vanderbilt Place, Nashville, TN 37235, U.S.A. Tel.: +1 615 936 7271; fax: +1 615 343 8495. E-mail: kevin.huang@vanderbilt.edu.

§Department of Economics, the University of Hawai'i at Manoa; e-mail: shengti@hawaii.edu.

1 Introduction

The relation between health and macroeconomy has received increasing attention. Issues concerning health and medical expenditure take center stage in many recent macroeconomic analyses and policy forums.[1] The work by Jones and Klenow (2011) illustrates the importance of health for national welfare (see, also, Murphy and Topel 2006, Hall and Jones 2007), while a growing literature explores the macroeconomic causes and implications of the long-run trend in medical expenditure.[2] The relation between health and macroeconomic development is at the core of the World Health Organization's Commission on Macroeconomics and Health (CMH). Health is also a key measure of national macroeconomic development in the United Nations' Human Development Index (HDI).

Empirical evidence shows a positive relation between health and long-run growth. In contrast, in industrialized economies, health tends to be negatively correlated with macroeconomic performance in the short run, improving in recessions and worsening in booms, even though medical expenditure generally declines during contractions and rises during expansions. Egan et al. (2013) stress the critical importance of such short-run outcome, i.e., the pro-cyclicality of mortality, for business-cycle study.

One purpose of this paper is to conduct a systematic investigation in the potential causes of the cyclical correlations between health and macroeconomic performance, in particular, the joint pro-cyclicality of health expenditure and mortality rate, a key feature of the data that we believe a satisfactory macro-health business cycle model should account for. To this end, we build in a real business cycle model endogenous survival probability dependent of health history, and three channels of endogenous health accumulation documented in health economics, biomedical science, public health, psychobiology, and biosociology: (1) health affects utility; (2) health affects productivity but depreciates with labor or production; and (3) health can be maintained or improved with medical care or leisure activity. This provides a framework for analyzing the cyclical properties of health and medical expenditure using the language and tools of modern dynamic macroeconomics. The structural approach allows us to decompose the contributions of the three channels to generating the business-cycle moments for health and other macroeconomic variables of interest, and to quantify the roles of their interactions.

[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, for example, Suen (2006), Hall and Jones (2007), Fonseca et al. (2009), and Zhao (2014). The welfare effects of health care reforms are studied by Feng (2008) and Jung and Tran (2009), and the welfare and labor market implications of employment-based health benefits in the US are investigated by Fang and Gavazza (2011) and Huang and Huffman (2014).

Our structural model calibrated to the US data does a good job in explaining the cyclical behaviors of key health variables. The model accounts for a majority of the standard deviations of mortality rate and health expenditure and, more important, it generates their joint pro-cyclicality, with a near perfect match with the data in the correlation of mortality rate and GDP. When examined in terms of the cyclical behaviors of traditional macroeconomic variables, the model does a similar job as does a standard RBC model, with marginal improvements in matching the volatilities of consumption and investment.

Importantly, our structural decomposition analyses suggest that the production channel (2) and the time channel (3) are key to accounting for the cyclical behaviors of mortality rate and health expenditure, while other moments of the data concerning the cyclical behaviors of traditional macroeconomic variables also favor variants of the model with the production and time channels, but without the utility channel (1), in presence.

This is related to another contribution of our paper. Motivated by the seminal work of Grossman (1972) that emphasizes a consumption value of health, the growing literature of macro-health models have mostly incorporated a consumption motive for health care. In contrast, this literature has paid little attention to the production and time channels. The results in this paper suggest that, at least for business cycle studies, the production and time channels could be more relevant than the utility channel in modeling the endogenous accumulation of health capital.

2 Empirical Evidence and Modeling Approach

2.1 The cyclical behavior of health and health expenditure

Empirical studies suggest that measures of health and macroeconomic conditions tend to move in opposite directions over business cycles. The evidence on counter-cyclical health, manifested by pro-cyclical mortality, holds for not only the US, but other OECD countries, regardless of the choices of data types or aggregation levels, econometric specifications, de-trending methods, or estimation procedures.

Among the most influential studies are Ruhm (2000, 2003, 2005, 2007) based on US state-level data. Using labor market conditions as business cycle indicators, these papers present striking evidence on the pro-cyclicality of mortality, and the result is found to be most significant for mid-year working age adults. Similar results are also established for Germany (e.g., Neumayer 2004), Spain (e.g., Tapia Granados 2005), and Japan (e.g., Tapia Granados 2008), applying similar approaches. Gerdtham and Ruhm (2006) generalize the results to 23 OECD countries using aggregate data over a time period longer than that examined by Ruhm (2000). Janko et al. (2013) apply a time series error correction approach to aggregate Canadian data and reach a similar conclusion.[3] Based on less aggregated Canadian data, Ariizumi and Schirle (2012) do not find a significant cyclical pattern in the mortality rates of infants and seniors, but they do find strong evidence of a significant pro-cyclical pattern in the mortality rates of mid-year working age adults.[4]

Our own empirical analysis based on long US time series data, covering the period 1960-2007, confirms the previous conclusion. To tease out long-run trends, we pass the raw data through the Hodrick-Prescott filter (i.e., the HP filter), and we use variations in de-trended GDP as a direct indicator of the business cycle, following the standard approach in modern dynamic macroeconomics. Our results support the previous findings on the counter-cyclicality of US national health, especially the health of working age population.[5]

To set an empirical target for our structural model (to be presented in Section 3), we report here the business cycle moments borne out by our data relevant for the working age population. All of our data are at the annual frequency and cover the period 1960-2007. Data on mortality rate, measured by the number of deaths per 1,000 mid-year working age (ages 15-60) adults, are from the World Bank World Development Indicators (i.e., WDI), while data on total real health expenditure are from OECD Health Data 2010 (i.e., OECD 2010). Total real health expenditure in a given year is divided by the size of working-age population in that year to obtain real health expenditure per working age person. Data on real GDP and other quantity variables per working age person are from the National Income and Product Account (i.e., NIPA), as typical in the business cycle literature.[6] We pass the natural logs of these quantity variables (including the real health expenditures per working age person) through the H-P filter with a value of 400 for the smoothing parameter.

Using these de-trended data, we calculate the statistical correlation between the cyclical components of mortality and real GDP to be 0.3874, and that of real health

[3] Using similar approaches to tease out long-run trends, Tapia Granados and Diez Roux (2009) report evidence on the counter-cyclicality of US national health for the period 1920-1940, an earlier episode not typically covered by the other studies.

[4] Early documentation of pro-cyclical mortality can be found in Ogburn and Thomas (1922) and Thomas (1927). This is confirmed for five European countries in an early study by McAvinchey (1988). There also exists evidence on pro-cyclical death rates in some less developed countries, such as Argentina (e.g., Abdala et al. 2000) and South Korea (e.g., Khang et al. 2005).

[5] Similar results hold when we de-trend the raw data by the Baxter-King filter (i.e., the BK filter or the band-pass filter), which also is a standard filter used in modern dynamic macroeconomics.

[6] We take out net exports from the GDP data to be consistent with our closed economy model. Our results do not change much if net exports are included in the GDP data.

expenditure and real GDP to be 0.3722, both at 1% significance level. This is to say that both mortality and health expenditure are pro-cyclical. Figure 1 displays the cyclical behaviors of mortality rate and health expenditure for the period covered in our study. The first column of Tables 2 and 3 reports various second moments for the variables of interest computed from the actual data, which will be compared against the respective moments computed from the artificial data generated from our structural model.

2.2 Endogenous survival probability and three channels of endogenous health accumulation

The structural model to be presented in the next section features endogenous survival probability that is dependent of health history, and three channels of endogenous health accumulation: 1) health affects utility; 2) health affects productivity but depreciates with labor or production; and 3) health is maintained\improved with medical care or leisure activity. These features are essential to the analysis of health, health expenditure, and allocation of time pertaining to health production.

The feature of endogenous survival probability captures a survival motive for health investment by allowing health to affect survival prospect and so life expectancy (e.g., Hall and Jones 2007, Zhao 2014, Halliday et al. 2014). This has a direct bearing on the value of statistical life studied in the literature (e.g., Viscusi and Aldy 2003). More importantly, it helps to build a link between the latent health stock and the observable mortality rate, permitting our model to talk directly to the data.

In addition to the value of enhancing life expectancy, being healthier could make people feel better, bringing them instantaneous satisfaction at any given date. The postulation that better health enhances household utility at any given date captures Grossman's (1972) notion of a consumption motive for health care. Furthermore, being healthier could make consumption and leisure activity more enjoyable. In other words, health is complementary to consumption and leisure, so better health increases the marginal utility of consumption and leisure. This proposition is supported by the findings of Viscusi and Evans (1990), Murphy and Topel (2006), Finkelstein et al. (2010), Scholz and Seshadri (2010), and Halliday et al. (2014). These motivate our model to include health stock as another term, additional to consumption and leisure, in households' period utility function.

Grossman's (1972) study also emphasizes an investment motive for health care in that health capital may enter as another productive factor, additional to physical capital and labor, into firms' production function.[7] After all, health may affect

[7]Grossman's (1972) notion of the investment motive for health care also has a sense that better

productivity similarly as knowledge, so in terms of modeling it is conceivable to treat health analogous to education. Yet, health may depreciate with labor or production, and this is viewed by Ruhm (2000) as a potentially important source of pro-cyclical mortality. Among the various categories of pro-cyclical fatalities observed from the data, some (e.g., those resultant from heart and liver diseases) are arguably related to pro-cyclical unhealthy factors (e.g., stress)[8] or behaviors (e.g., cigarette, liquor, or junk food consumption),[9] while others stem directly from pro-cyclical motor vehicle accidents[10] and other accidents. Below we present our own evidence concerning an important category of these "other accidents", namely, work-related fatal injuries.

Comprehensive counts of fatal work injuries are produced by the Bureau of Labor Statistics (BLS) Census of Fatal Occupational Injuries (CFOI).[11] We obtain from the CFOI annual data on the number of fatal work injuries for the period 1992-2010.[12] The number in a given year is divided by the size of working-age population in that year. We pass the natural log of this variable through the H-P filter with a value of 400 for the smoothing parameter. H-P filtered output and labor per working age person for the same period are obtained in a similar way as described in Section 2.1. Using these de-trended data, we calculate the statistical correlation between the cyclical components of fatal work injuries and annual working hours to be 0.48 at 5% significance level, and that of fatal work injuries and output to be 0.60 at an even more significant 1% level. This is to say that fatal work injuries are strongly pro-cyclical. Figure 2 displays the cyclical behaviors of fatal work injuries for the period studied above.

The above evidences motivate our model to include in the production function, along with physical capital and labor, health capital as another productive factor, that depreciates with labor or output, or even with health harmful consumption such as smoking and drinking.

The proposition and supportive evidence that not only medical care but leisure

health may reduce sick time and thus make more time available for work or leisure. Incorporating this feature into our model would only slightly strengthen the results of this paper.

[8]Sparks et al. (1997) provide a comprehensive survey of overwhelming evidence.

[9]Corroborating evidence is provided by Xu and Kaestner (2010) and Coleman and Dave (2014). See, also, Ruhm (2000).

[10]This evidence is reinforced by Miller et al. (2009), especially for working age population.

[11]The CFOI is a federal-state cooperative program that has been implemented in all 50 states and DC since 1992. To compile counts that are as complete and as accurate as possible, the census uses multiple sources to identify, verify, and profile fatal worker injuries. To ensure that fatal injuries are work-related, cases are substantiated with two or more independent source documents such as death certificates, workers' compensation reports, and federal and state agency administrative reports, or a source document and a follow-up questionnaire.

[12]The data are downloadable at http://www.bls.gov/iif/oshwc/cfoi/cfch0009.pdf.

can be important for maintaining or improving health have long been documented in the health economics literature.[13] Corroborating 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,[14] while some studies find reduced medical expenditure from increased leisure time.[15] Pressman et al. (2009) establish a general link between a wide array of leisure activities[16] and a broad variety of health benefits.[17] Caldwell (2005), Russell (2009), and Payne et al. (2010) provide a comprehensive review of the empirical evidence on the importance of leisure in achieving and maintaining good health, and an intuitive account of the prevention, coping, and transcendence mechanisms by which leisure enhances physical, mental, social, and cognitive health.[18] 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, World Bank, and Conference Board. These studies confirm that both medical care and leisure make significant contributions to maintaining and improving health, with some elasticity of substitution between the two inputs in health production.

This naturally leads us to conjecture, because of the pro-cyclical labor and thus counter-cyclical leisure changes across the business cycle, the potential importance

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[13]See Grossman (1972), Gronau (1977), Kenkel (1995), Sickles and Yazbeck (1998), Ruhm (2000), Contoyannis and Jones (2004), Scholz and Seshadri (2010), and Insler (2011). He et al. (2013) and He and Huang (2015) provide a comprehensive review and discussion of the evidence.

[14]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. See Watson (1988), House et al. (1988), Simon (1991), Ulrich et al. (1991), Haskell (1994), Benca and Quintas (1997), Staats et al. (1997), Cohen et al. (1997), Szabo et al. (1998), Tominaga et al. (1998), Gump and Matthews (2000), Diener et al. (2002), Batty et al. (2003), Ayas et al. (2003a), Ayas et al. (2003b), Ryff et al. (2004), Sacker and Cable (2005), and Warburton et al. (2006).

[15]See Colditz (1999), Pratt et al. (2000), Wang and Brown (2004), and Brown et al. (2005).

[16]Examples of such leisure activities are having hobbies, playing sports, socializing, spending time unwinding or in nature, visiting friends or family, and going on vacation or to clubs or religious events.

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

[18]See, also, Lazarus et al. (1980), Iso-Ahola and Weissinger (1984), Weissinger and Iso-Ahola (1984), Kleiber (1985), Tinsley and Tinsley (1986), Caldwell and Smith (1988), Iso-Ahola (1988), Hull (1990), Chalip et al. (1992), Coleman and Iso-Ahola (1993), Iwasaki and Mannell (2000), Iwasaki and Schneider (2003), and Iwasaki et al. (2006).

of the time channel in generating the counter-cyclical mortality changes[19] in the face of the pro-cyclical variations in health spending.

More direct evidence on the pro-cyclical behavior of time allocated to maintaining or improving health is found from the BLS American Time Use Survey (ATUS).[20] Applying Tobit regression to pooled data observed at the monthly frequency from ATUS 2003-2009, and using state-level labor market conditions as business cycle indicators, Edwards (2011) finds that, while labor time falls in economic downturns, time spent sleeping, eating, telephoning, traveling, and especially socializing and relaxing, all increases significantly. Aguiar et al. (2011) report about 50% of the foregone labor time during the recent recession relocated to sleeping and exercising, etc., and 5% to self-caring. Similar evidence is found by Coleman and Dave (2011). These all suggest the pro-cyclical allocation of time to health production.

All in all, these motivate our mode to incorporate a health production function with both health care and leisure as inputs.

3 Model

The economy is populated by a continuum of agents. Depending on his health history $h^t \equiv (h_0, h_1, ...h_t)$, a representative agent has a probability $\pi(h^t)$ to survive through period t. As in Hall and Jones (2007), we impose the Markov property on the survival prospect so that the probability of surviving through period t conditional on having survived through period $t-1$ depends only on the agent's date-t health stock h_t, where this conditional probability $\Psi(h_t) \equiv \pi(h_t|h^{t-1})$ is an increasing function of h_t.

At date t, a living agent derives utility from not only consumption c_t and leisure l_t, but his health stock h_t, according to a period utility function $U(c_t, l_t, h_t)$, which is monotone, concave, and twice continuously differentiable.

Total output y_t is produced using not only physical capital k_t and labor n_t, but health capital h_t, under total factor productivity z_t according to $y_t = F(k_t, n_t, h_t; z_t)$, which is a monotone, quasi-concave, and twice continuously differentiable function.

The law of motion for physical capital takes the standard form $k_{t+1} = (1-\delta_k)k_t + i_t$ where δ_k is physical capital depreciation rate and i_t is physical capital investment.

Health capital depreciates with labor according to a monotone, convex, and twice continuously differentiable function $\Delta(n_t)$.[21] On the other hand, health investment

[19]The spirit is also envisioned by Ruhm (2000).

[20]The ATUS is a repeated cross sectional survey beginning in 2003 of individuals in US households, with samples drawn from the Current Population Survey (CPS). It records, via telephone interviews, how people allocate their time, using a 24-hour diary, across over 400 time use categories.

[21]Assuming instead that health depreciates with output and\or even with bad consumption would

is created using medical commodity m_t and leisure l_t according to $H(m_t, l_t)$, which is a monotone, quasi-concave, and twice continuously differentiable function. The law of motion for health capital is then given by $h_{t+1} = [1 - \Delta(n_t)]h_t + H(m_t, l_t)$.

To close the model, we recognize the resource constraint for goods, $c_t + i_t + m_t = y_t$, and for time, $l_t + n_t = 1$, and postulate a stochastic driving process for TFP.

A representative agent solves the following problem:

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

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

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

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

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

which equates the 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

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

which equates the cost of leisure, in terms of the foregone marginal product of labor, with the benefit from having additional leisure summarized by the right-hand side of (8), including saved consumption while maintaining utility (the first term), and saved medical commodity, by retaining more existing health capital (the second term), and in creating health investment (the third term), while maintaining health stock.

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not change the conclusion of this paper. See Section 6 for some details.

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

$$\frac{U_c(t)}{H_m(t)} = \beta \mathrm{E_t} \Psi(h_{t+1}) \tag{9}$$
$$\left\{ U_h(t+1) + U_c(t+1)F_h(t+1) + \frac{\Psi'(h_{t+1})}{\Psi(h_{t+1})} U(t+1) + [1 - \Delta(n_t)] \frac{U_c(t+1)}{H_m(t+1)} \right\}$$

which equates the foregone marginal utility from relocating consumption to medical commodity for health investment with the present value of expected future benefit from having additional health capital. The future benefit is, in addition to enhanced survival prospect, captured by the four terms inside the bracket on the right-hand side of (9), including marginal utilities derived from the additional health capital directly (the first term), and from additional consumption that is made available by increased output brought about by the additional health capital (the second term), salvaged utility due to extended life span generated from the additional health capital (the third term), and a continuation value in terms of savings on future health investment due to incomplete depreciation of health capital (the fourth term).

Equations (2)-(9) form a complete system of equilibrium conditions. Because the system cannot be solved analytically, we approximate the true solution numerically by solving for a log-linear approximation around the system's steady state, which is obtained by setting σ_ϵ to 0. We use the solution to generate simulated moments that can then be compared with actual moments computed from the data. For this exercise, we follow the business cycle and other relevant literatures to parameterize the preferences and technologies, and to calibrate the model by matching relevant steady-state conditions with corresponding conditions that represent the long-run average behaviors of the US economy, or applying standard parameter values used in the business cycle and other relevant literatures.

4 Parameterization and Calibration

We postulate the following functional forms:

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

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

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

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

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

The survival probability (10) takes the same parametric form as in Zhao (2014), implying a date-t death rate of $e^{-\kappa h_t}$. Functions (11)-(13) parameterize preferences and technologies similarly as Greenwood et al. (1988, GHH henceforth), highlighting the substitutable uses of time in affecting utility and production, and treating labor as utilization of health capital analogous to how GHH treat utilization of physical capital. The creation of health investment (14) is parameterized in light of the studies by Sickles and Yazbeck (1998) and He et al. (2013).

We set κ equal to 22.8248, to be consistent with a long run average mortality rate of 0.8868% in the US (1960-2007).

We set the annual discount factor β to 0.966 in order to match a long run physical capital-output ratio of 3.32, and 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 are standard values used in the literature based on the postwar US data (e.g., Cooley and Prescott 1995, Nadiri and Prucha 1996, Chen et al. 2009).

A physical capital-output ratio of 3.32 and physical capital depreciation rate of 0.076 imply an investment-output ratio of around 25% and thus a ratio of total consumption (including medical expenditure) to output of around 75%, in line with observations from the US National Income and Product Account (1960-2007). The average US medical expenditure-output ratio for the same period computed from OECD Health Data 2010 is 10.2%, so the ratio of consumption (exclusive of medical expenditure) to output is 64.8%. This implies a value 0.5733 for λ, which measures the importance of consumption relative to health in preferences. We set η, whose inverse measures the elasticity of substitution between consumption and health in preferences, to 8.85, consistent with the studies by Viscusi and Evans (1990), Murphy and Topel (2006), Finkelstein et al. (2010), and Halliday et al. (2014). Some studies adopt the standard Cobb-Douglas specification for the consumption-health bundle in preferences (e.g., Fonseca et al. 2008, Jung and Tran 2011) or use a value of η even lower than unit (e.g., Yogo 2009, Scholz and Seshadri 2010). Our results are robust to these alternative choices of η. We assign a value 2.0684 to ϕ, which gauges the importance of leisure relative to consumption\health in preferences, in order to ensure that labor takes up just slightly less than one-third of discretionary time. The parameter χ is related to the Frisch labor supply elasticity, and we set it to 2, which is a moderate value used in the business cycle literature.

As pointed out by Hall and Jones (2007), the term b in (11) is meant to ensure positivity of the period utility so as to make it worthy to enhance life expectancy. This term has a direct bearing on the value of statistical life, which, in our model, as in Hall and Jones (2007) and Zhao (2014), corresponds to the marginal cost of saving a life, measured by VSL $= [\partial\Psi(h)/\partial m]^{-1}$. Substituting this measure into the steady state versions of (7)-(9) yields a relation between b and the steady state value of VSL. We set b to 4.38, in order to match this steady state VSL in our model with the mean VSL observed in the data for working age Americans reported by the US Food and Nutrition Service (USDA) and Environmental Protection Agency (EPA).[22] We verify that b so calibrated is indeed big enough to guarantee that the flow utility is always positive under all circumstances in our simulations.

One strand of the biology literature on natural aging of human body finds that as humans age they develop an increasing number of disorders, which is referred to as "deficits". Based on data from four developed countries including the US, it shows that the average individual accumulates about 3 to 4% more deficits per year (e.g., Dalgaard and Strulik 2010). We set δ_h, which in our model measures the natural depreciation rate of health capital, to 4% in the baseline calibration, and we consider $[3\%, 6\%]$ an empirically plausible range for this parameter in light of this literature and corroborating evidence for US working age population (e.g., Fonseca et al. 2008, Scholz and Seshadri 2010, Zhao 2014). Available data do not also allow us to pin down a definitive value for the curvature parameter ϖ. We consider a baseline value of 4, implying labor or production related depreciation in health stock of 0.26% per year, which seems quite conservative. Our results are robust to alternative values of ϖ, and to variations of δ_h within its empirically plausible range.

Concerning health production function (14), we set ω to 1 in light of the empirical estimates by Sickles and Yazbeck (1998) and He et al. (2013). We set $B = 0.0428$ and $\theta = 0.3094$, in order to be consistent with the average shares of real GDP (10.2%) and of total private consumption expenditure (13.6%) 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 consider 1 to be the baseline value of ξ following Grossman (1972) and much of the macro-health literature. Ehrlich and Chuma (1990) argue that some degree of decreasing returns to scale may be more appropriate for health production technology in this type of models. Our conclusion is robust even if we lower ξ to 0.5, a value suggested by Ehrlich and Chuma (1990).

For the parameters governing the TFP process, we normalize its unconditional

[22]See, also, Table 12 in Viscusi and Aldy (2003) and Table 1 in Hall and Jones (2007).

mean z to 1, and we set the autoregressive coefficient ρ_z to 0.95 and the standard deviation of innovation σ_ϵ to 0.0173, as is standard in the business cycle literature.

The baseline values of parameters are summarized in Table 1.

5 Main Results

As a standard approach in business cycle study, we evaluate our model's performance by comparing various second moments for the variables of interest computed from the artificial data produced by the structural model against the corresponding moments computed from the actual data.

We report in Table 2 the correlations with and the standard deviations relative to GDP of five variables, including consumption (exclusive of health care), investment, employment, health care, and mortality rate, computed from the data (first column), the baseline model (second column), and six versions of the baseline model in which one or two of the three channels of endogenous health accumulation are shut off (third to eighth columns).[23] As noted before, the statistics for the US economy are computed based on HP-filtered data covering the period 1960-2007. The statistics for the model are computed based on HP-filtered artificial time series and are averages over 200 simulations of 150 periods each.

As can be seen from comparing the first two columns of the table, the model does a fairly good job in explaining the cyclical behaviors of the two health variables. The model accounts for 70% and 82% of the standard deviations of mortality rate and health expenditure in the data. More important, it generates the joint pro-cyclicality of these two variables, the key feature of the data that any successful macro-health model should replicate. For mortality rate, the match in the degree of pro-cyclicality between the model and the data is almost perfect,[24] although for health expenditure, the correlation with GDP is much higher in the model than seen from the data.[25]

[23] In each variant of the baseline model, certain parameters are re-calibrated to match the relevant steady-state conditions in the model with the corresponding moment conditions for the US economy. In particular, the unconditional mean of TFP is also adjusted accordingly to ensure that the steady-state behavior of each variant model remains consistent with the long-run average behavior of the US economy not only in the relevant ratios but in levels as well. Our decomposition results do not change dramatically when we do not re-calibrate the variants of the baseline model.

[24] It is worth noting that, when using the labor market condition as a business cycle indicator, the model does an equally successful job in accounting for the pro-cyclical behavior of mortality rate, e.g., the correlation between mortality rate and employment is 0.45 in the model, matching well the correlation between work-related fatal injuries and working hours of 0.48 in CFOI data.

[25] We conjecture that incorporating uninsurable idiosyncratic health shocks may help bring the degree of pro-cyclicality in health expenditure in the model closer to what is seen from the data.

When examined in terms of the cyclical behaviors of traditional macro variables, our model does a similar job as a standard RBC model, one obtained by taking all of the three channels of endogenous health accumulation along with the feature of endogenous survival probability out of the framework, but not presented here due to the space constraint, with marginal improvements in matching the volatility of consumption (still lower than in the data but higher than in the standard model) and of investment (slightly lower instead of moderately higher than in the data).

We are mostly interested in examining the variants of the baseline model with one or two of the three channels of endogenous health accumulation remaining in the framework, since this would allow us to decompose the contributions of the three channels to generating the business-cycle moments for the variables of interest, and to quantify the roles of their interactions. We turn now to accomplish this task by examining the following six variants of the baseline model:[26]

With only utility channel

This version of the model is obtained by replacing h_t with 1 in (12) and taking out n_t^{ϖ}/ϖ from (13), along with setting $\theta = 1$ in (14).

With only production channel

This version of the model is obtained by setting $\lambda = 1$ in (11) and $\theta = 1$ in (14).

With only time channel

This version of the model is obtained by setting $\lambda = 1$ in (11) while replacing h_t with 1 in (12) and taking out n_t^{ϖ}/ϖ from (13).

With both utility and production channels

This version of the model is obtained by setting $\theta = 1$ in (14).

With both utility and time channels

This version of the model is obtained by replacing h_t with 1 in (12) and taking out n_t^{ϖ}/ϖ from (13).

With both production and time channels

This version of the model is obtained by setting $\lambda = 1$ in (11).

The structural decomposition results, as reported in the third to eighth columns of Table 2, show that the production and time channels are key to accounting for the cyclical behaviors of health care and mortality rate, while the other moments of the data also favor variants of the model with the production and time channels but

[26] The re-calibration details for these variants of the baseline model (see Footnote 23) are not reported here in order to conserve space, but they are available upon request from the authors.

without the utility channel.

To put this into a quantitative perspective, we first note that the utility channel by itself (third column) generates too low a correlation with and too high a standard deviation relative to GDP of mortality rate, 0.05 and 0.65, respectively, compared to the data of which the two statistics are 0.39 and 0.13. In contrast, the two statistics generated by the production channel alone (fourth column), 0.24 and 0.14, and by the time channel alone (fifth column), 0.45 and 0.13, match the data well. Adding the utility channel on top of another channel either makes no contribution to improving performance (sixth vs. fourth columns), or turns a good performance into a bad one (seventh vs. fifth columns). By contrast, combining the other two channels generates a perfect match in the degree of pro-cyclicality while maintaining a fairly good match in the volatility of mortality rate (eighth column).

Second, the utility channel by itself also generates too high a standard deviation of health care expenditure relative to GDP compared to the data (2.42 vs. 0.97), while the standard deviation generated by the production or time channel alone is much closer to the data (0.89 and 0.46). Similarly as before, adding the utility channel on top of another channel either makes no contribution to improving performance or turns a good performance into a bad one, while, by contrast, combining the other two channels maintains a fairly good match in the volatility of health care expenditure. It is worth noting that, all of the three channels, either by themselves or together, generate too high a correlation between health care expenditure and GDP, with some notable exception for the time channel when standing alone by itself that generates a somewhat lower correlation (even though still higher than seen in the data).[27]

Not only do the data on health but that on traditional macroeconomic variables favor the variants of the model with the production and time channels but without the utility channel. To see this, note that, the standard deviations of consumption and employment relative to GDP in the sole presence of the utility channel are too low (0.28 and 0.10) compared to the data (0.78 and 0.67). In contrast, the two standard deviations in the sole presence of the production channel, 0.59 and 0.30, or of the time channel, 0.66 and 0.34, are much higher and closer to the data. Adding the utility channel on top of one of the other two channels either does not raise, or significantly lowers the volatilities, worsening the matches with the data dramatically, while, by contrast, combining the other two channels maintains continuously higher volatilities of consumption and employment that are much closer to the data.

The structural decomposition results analyzed above all seem to point to the same conclusion about the relative importance of the production and time channels but insignificance of the utility channel for a macro-health model to explain the cyclical

[27]See Footnote 25 on this issue.

behaviors of not only health variables but also traditional macroeconomic variables. We have done many sensitivity analyses and find that this conclusion is fairly robust.

For instance, the conclusion is even somewhat strengthened when the GHH utility function in (11) is replaced with the CRRA utility function below:

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

To see this, we re-solve the model and all of its variants under (15), with necessary re-calibrations (see Footnote 23), and we report the results in Table 3. Examining the table in a similar way as we did above to Table 2 confirms all of the symptoms in favor of the production and time channels but against the utility channel under the GHH preferences remaining under the CRRA preferences, plus one symptom that shows up here though not there. That is, in the sole presence of the utility channel, there is too low a correlation of employment with GDP compared to the data (0.18 vs. 0.80), while, by contrast, in the sole presence of the production or time channel, the correlation is much closer to the data (0.93 and 0.92). Also, adding the utility channel on top of one of the other two channels either does not change, or lowers the correlation to a negative value (-0.40), which is totally at odds with the data, while, in contrast, combining the other two channels retains a correlation that is much closer to the data.

Overall, the model with the CRRA preferences in place of the GHH preferences continues to do a decent job in accounting for the cyclical behaviors of health and traditional macroeconomic variables, provided it incorporates the production channel and\or the time channel, or all the three channels. There is one notable exception, that is, the standard deviation of employment relative to GDP is much lower under the CRRA preferences than under the GHH preferences, a well-known phenomenon (due to the presence of an income effect on labor supply under the CRRA preferences but lack thereof under the GHH preferences), that adding the channels of endogenous health accumulation does not make vanishing.

6 Other Sensitivity Analyses

In this section, we undertake two additional sensitivity analyses that we think are interesting, either because they impinge in alternative modeling of a core mechanism driving a pro-cyclical mortality rate, which is a main empirical target that we think any satisfactory macro-health business cycle model ought to match, or because they pertain to the robustness of this empirical target itself.

6.1 Modeling health harmful consumption

As documented in Section 2, among the various categories of pro-cyclical fatalities observed from the data, some are related to pro-cyclical consumption of cigarette, liquor, junk food, and risky entertaining activity, which may generate instantaneous satisfaction but harm health. To capture utility gain from such bad consumption, we replace the period utility function in (11) with

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

for some $\upsilon > 0$, where $c_{g,t}$ and $c_{b,t}$ denote health neutral and harmful consumption, respectively, while to capture health loss due to the bad consumption, we replace the health capital depreciation function in (13) with

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

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

The way of modeling health harmful consumption in (16)-(17) above introduces two additional parameters, υ and ζ. Recall in Section 4 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 re-calibrated along with these eight parameters so that the steady-state behavior of the model remains consistent with the long-run average behavior of the US economy not only in the relevant ratios but in levels as well (see Footnote 23).

We find that incorporating bad consumption slightly improves our model's fit. The standard deviations of mortality rate and health care both increase marginally, from 0.09 and 0.79 in the the baseline model, to 0.13 and 0.81 here, to account for a larger fraction of the data for which the two statistics are 0.13 and 0.97. The fit in the correlation between mortality rate and GDP also improves marginally, to a near perfect level (0.39 in the model vs. 0.39 in the data), with the fit in other cyclical moments remaining similar as in the baseline model.

To check the robustness of this result, we also conduct our 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, rather than treating it as an additively separable term as in (16).

The cyclical performance of all variables, except for consumption, remains similar with (18) as under (16), and reasonably close to the data. That said, the consumption data favor (16), under which the marginal utility of health harmful consumption is independent of health status, against (18), under which it is decreasing with health status. Under (18), health neutral consumption is significantly counter-cyclical, with a correlation with GDP of -0.46, and excessively smooth, with a standard deviation relative to GDP of 0.01, while health harmful consumption is excessively volatile, with a standard deviation relative to GDP of 6.63, totally at odds with empirical observations. In contrast, as noted above, the consumption moments under (16) are much more reasonably looking and closer to the data.

6.2 Accounting for stronger pro-cyclicality of mortality rate and health care in an earlier episode

As a major empirical target for a macro-health business cycle model, pro-cyclicality of mortality rate, and of health care, was stronger in an earlier episode (1972-1991) studied by Ruhm (2000) than in the longer period (1960-2007) covering some even earlier and more recent years studied above.[28]

[28]Figure 1 reveals some phase shifts in mortality rate and health expenditure during late 1990s that significantly weakened their correlations with GDP for that period. We suspect this had some to do with the medical technological breakthrough known as “cocktail therapy” discovered in 1996, which attributed to the subsequent sharp decline in mortality rate. According to CDC, the decline was mainly caused by the substantial drop in mortality rate due to HIV infection and it was mostly significant for working ages 25-44. This is perhaps why no such phase shift is observed from Figure 2 for work-related fatal injuries (for the period for which the data are available) that seem to be as pro-cyclical in the 1990s as in more recent years. An in-depth investigation of this issue is beyond the scope of this paper. For a related study, see Ruhm (2013).

It is thus fitting to test our model's ability in accounting for this earlier episode. To do so, we compute the business cycle moments borne out by the data covering the period 1972-1991 following the procedure described in Section 2, calibrate our model to the data covering this same period following the procedure described in Section 4, and compute the corresponding moments from the artificial data generated by the calibrated model following the procedure described in Section 5.

Table 4 reports the results. It is clear that the model continues a similarly good performance in replicating the stronger pro-cyclicality but lower volatility of the two health variables, and the cyclical properties of traditional macroeconomic variables, for this earlier episode.

6.3 Remarks

We have conducted many more sensitivity analyses than discussed here, and found that our basic conclusions hold quite generally.[29] In general these changes in model features or parameter values or sample periods have some quantitative influence on the results – sometimes very modestly, and other times to a greater degree – but in no case they alter the main nature of the results. Overall, the model provides a fairly successful account of the cyclical behaviors of health and other macroeconomic variables, and it is the production and\or time channels, not the utility channel, of endogenous health accumulation that is the key to such success.

7 Conclusion

The model that we have developed in this paper is admittedly stylized in the tradition of the standard real business cycle literature. Nonetheless, we view it as a necessary first step in building more sophisticate 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 three channels of endogenous health accumulation documented in several scientific disciplines, as they pertain to the cyclical behaviors of health and other macroeconomic variables. Viewed from this perspective, we take the framework presented here as a springboard for further quantitative research that needs to take into account more frictions and shocks.

[29]These additional sensitivity analyses are not reported here due to the space constraint, but they are available upon request from the authors.

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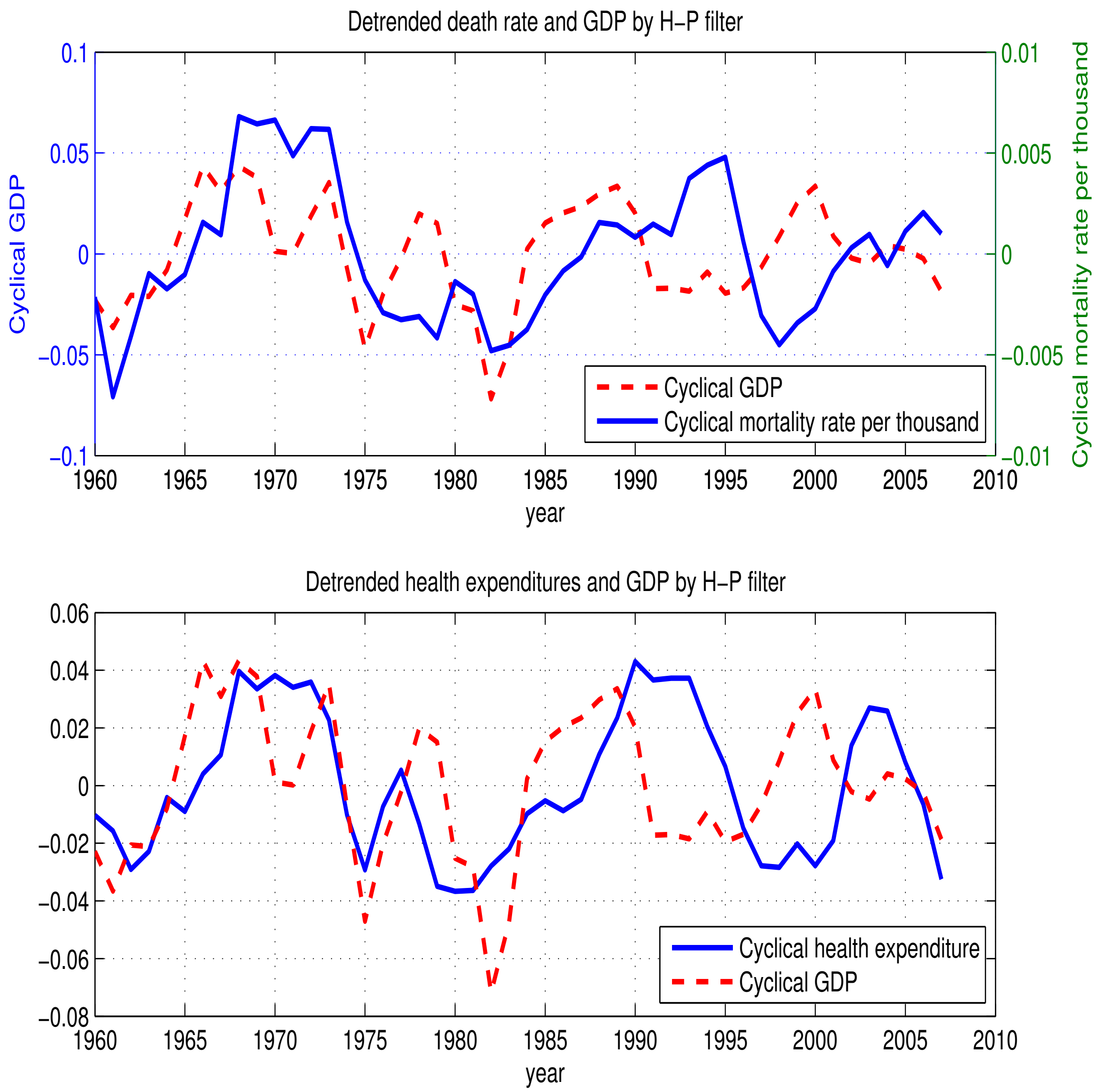

Figure 1. Cyclical behavior of mortality rate and health expenditure

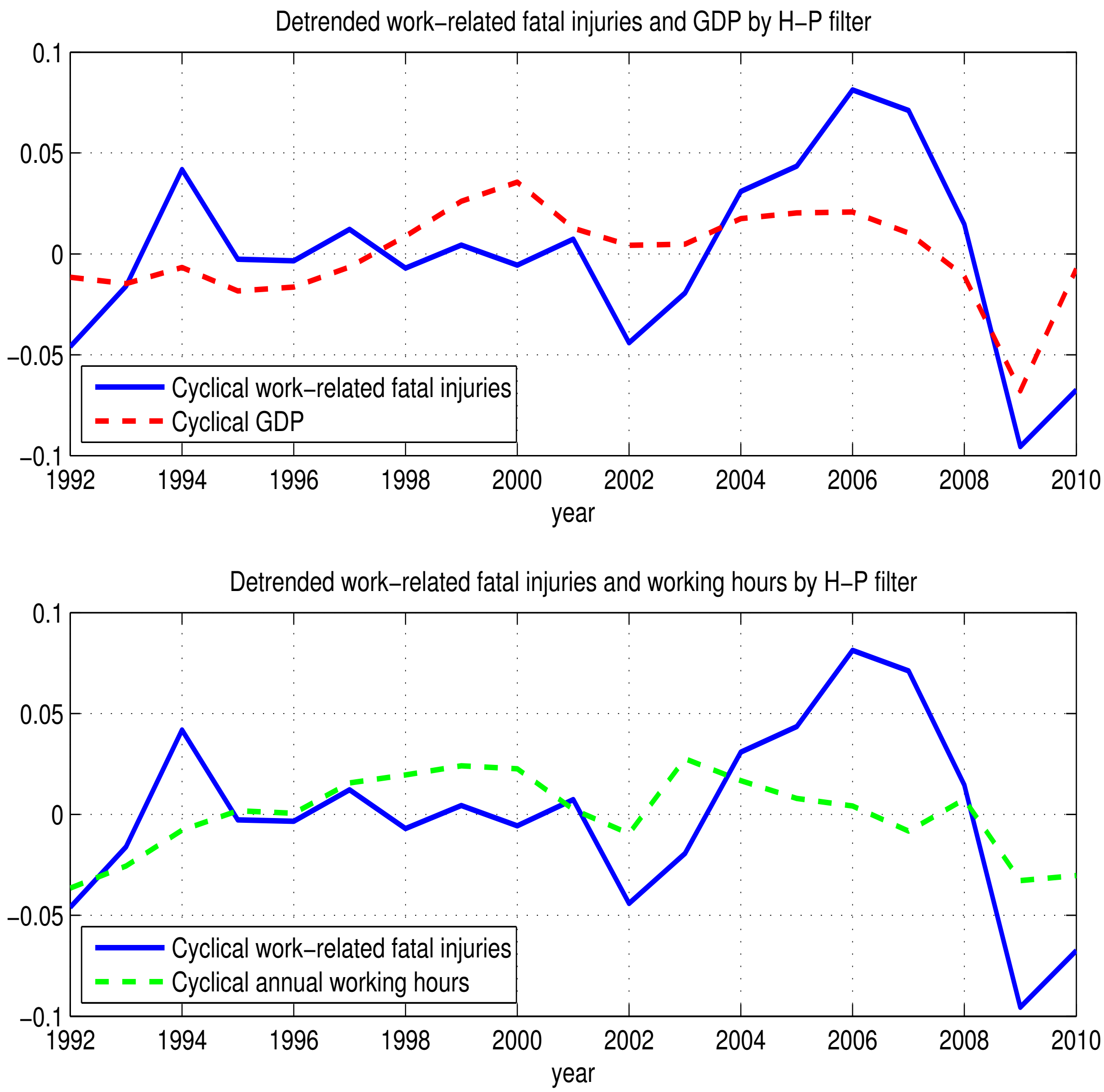

Figure 2. Cyclical behavior of work-related fatal injuries

Table 1: Baseline Parameter Values

Parameters		Values
	Survival Motive	
κ	curvature parameter in survival probability function	22.8248
b	constant term in period utility function	4.38
	Utility	
β	subjective discount factor	0.966
λ	share of consumption in consumption-health bundle	0.5733
η	elasticity of substitution between consumption and health	8.85
ϕ	weight of leisure	2.0684
χ	inverse related to 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 health depreciation function	4
θ	share of medical commodity in health investment	0.3094
ω	elasticity of substitution between health care and leisure	1
B	technology level in health investment	0.0428
ξ	returns to scale in health investment	1

Table 2: Business Cycle Statistics[a]

Statistics	Data[b]	Model	Decomposing channels					
			util	prod	time	util&prod	util&time	prod&time
Correlations with GDP								
Consumption	0.93	0.97	0.87	0.97	0.98	0.97	0.91	0.97
Investment	0.87	0.98	0.99	0.98	0.98	0.98	0.99	0.98
Employment	0.80	0.99	0.99	0.99	0.99	0.99	0.94	0.99
Health care	0.37	0.97	0.99	0.98	0.74	0.98	0.99	0.97
Mortality rate	0.39	0.41	0.05	0.24	0.45	0.25	0.06	0.39
Standard deviations relative to GDP								
Consumption	0.78	0.60	0.28	0.59	0.66	0.60	0.31	0.60
Investment	2.35	2.22	2.42	2.19	2.22	2.18	2.38	2.22
Employment	0.67	0.28	0.10	0.30	0.34	0.30	0.05	0.28
Health care	0.97	0.79	2.42	0.89	0.46	0.86	2.30	0.80
Mortality rate	0.13	0.09	0.65	0.14	0.13	0.13	0.58	0.10

[a]The model's statistics are computed based on HP-filtered artificial time series and are averages over 200 simulations of 150 periods each.

[b]The statistics are computed based on HP-filtered data for the US covering the period 1960-2007.

Table 3: Business Cycle Statistics (Model with CRRA Preferences)[a]

Statistics	Data[b]	Model	Decomposing channels: util	prod	time	util&prod	util&time	prod&time
Correlations with GDP								
Consumption	0.93	0.92	0.89	0.92	0.93	0.92	0.89	0.92
Investment	0.87	0.97	0.99	0.97	0.97	0.97	0.99	0.97
Employment	0.80	0.91	0.18	0.93	0.92	0.93	-0.40	0.92
Health care	0.37	0.97	0.99	0.98	0.83	0.98	0.99	0.97
Mortality rate	0.39	0.35	0.10	0.21	0.41	0.21	0.13	0.35
Standard deviations relative to GDP								
Consumption	0.78	0.52	0.27	0.51	0.56	0.52	0.28	0.52
Investment	2.35	2.47	2.50	2.46	2.52	2.45	2.53	2.48
Employment	0.67	0.08	0.03	0.08	0.09	0.08	0.04	0.08
Health care	0.97	0.83	2.23	0.93	0.50	0.93	2.15	0.87
Mortality rate	0.13	0.15	0.47	0.17	0.13	0.16	0.47	0.15

[a]The model's statistics are computed based on HP-filtered artificial time series and are averages over 200 simulations of 150 periods each.

[b]The statistics are computed based on HP-filtered data for the US covering the period 1960-2007.

Table 4: Business Cycle Statistics for an Earlier Episode[a]

Statistics	Data[b]	Model
Correlations with GDP		
Consumption	0.95	0.97
Investment	0.56	0.98
Employment	0.94	0.99
Health care	0.91	0.97
Mortality rate	0.53	0.43
Standard deviations relative to GDP		
Consumption	0.82	0.61
Investment	2.05	2.21
Employment	0.71	0.28
Health care	0.61	0.78
Mortality rate	0.09	0.08

[a]The model is calibrated to the US data covering the period 1972-1991 and its statistics are computed based on HP-filtered artificial time series and are averages over 200 simulations of 150 periods each.

[b]The statistics are computed based on HP-filtered data for the US covering the period 1972-1991.