Center for
Economic Theories and Policies
Sofia University St. Kliment Ohridski
Faculty of Economics and Business Administration

ISSN: 2367-7082

Bulgarian Economic Papers

US Health and Aggregate Fluctuations

Aleksandar Vasilev

BEP 01-2015
Publication: January 2015

US Health and Aggregate Fluctuations

Aleksandar Vasilev*

December 20, 2014

Abstract

This paper aims to shed light on the importance of health considerations for business cycle fluctuations and the effect of health status on labor productivity and availability of labor input for productive use. To this end, Grossman's (2000) partial-equilibrium framework with endogenous health is incorporated in an otherwise standard Real-Business-Cycle (RBC) model. Health status in this setup is modelled as a utility-enhancing, intangible, and non-transferrable capital stock, which depreciates over time. The household can improve their health ("produce health") through investment using a health-recovery technology. The main results are: (i) overall, the model compares well vis-a-vis data; (ii) the behavior of the price of healthcare is adequately approximated by the shadow price of health in the model; (iii) the model-generated health variable exhibits moderate- to high correlation with a large number of empirical health indicators.

Keywords: real business cycles, health status, health investment

JEL Classification: E32, E37, I11, I13

*Asst. Professor and CERGE-EI Affiliate Fellow, Department of Economics, American University in Bulgaria, 1 Georgi Izmirliev Sq., Blagoevgrad 2700, Bulgaria. Tel: 00 359 73 888 482. I would like to thank Kaloyan Ganev, Andrey Vassilev, Henrik Egbert, and the participants at the regular seminar of the Center for Economic Theories and Policies at Sofia University, Oct. 18, 2014, for their constructive comments. E-mail for correspondence: avasilev@aubg.bg.

1 Introduction

Sick time represents a significant proportion (3-9.5%) of total working time in OECD countries (CES-Ifo Dice Database 2011). Time off work due to illness (of a worker and/or of a sick family member) is different from leisure, as it represents an inefficient use ("waste") of resources. In particular, workers' (individual and group) health status affects both productivity and the availability of labor input in general. In addition, sick leave is part of the benefits package, and comes largely at the expense of the employer, thus effectively increasing labor costs. The total amount of paid sick days thus imposes a non-trivial cost on the OECD economies, which ranges between 11.6-17.9 % of GDP (OECD 2009).

This paper focuses on the relevance of health for the aggregate economy. The study addresses the importance of health status as a source of business cycle fluctuations, and develops a plausible transmission mechanism to shed light on the important role of health in macroeconomic context. To this end, an otherwise standard Dynamic-Stochastic-General-Equilibrium (DSGE) model is augmented with health channel and calibrated in the Real-Business-Cycle (RBC) tradition.

In US data, health of a nation measures vary over the business cycle and co-move with real output and productivity. That is an indication that good health is at least partially responsible for higher productivity. In addition, by endogeneizing health, we will isolate part of the exogenous Total Factor Productivity (TFP) variability. Therefore, our work contributes to the agenda, set by Prescott (1998), to decrease the role of exogenous technology shocks in the propagation of business cycles. The model in this paper expands on Grossman's (1972, 2000) partial equilibrium setups.

In this paper, model health is to be interpreted as the general "fitness" of the population. For example, in the American Time Use Survey (ATUS) from 2009, people who exercise spend a third of their leisure doing sports. In this sense, as pointed by Zweifel (2009, Ch.3) "health can be produced," and sport can be viewed as a technology that replenishes health. In addition, health can be regarded as a special type of capital that is subject to depreciation, but can also be recovered through investment in health. Individuals can dedicate time and effort to improve health ("produce health"), e.g. through exercising, vacation, good diet and recreation, but such investment using a health-recovery technology will produce uncertain outcomes. More specifically, the health technology will be subject to health shocks. On the other hand, health stock is also intangible and non-transferrable (there is no market for health), which distinguishes it from other forms of capital. The main results from this study are: (i) overall, the model compares well vis-a-vis data; (ii) the behavior of the price of healthcare is adequately approximated by the shadow price of health in the model; (iii) the model-generated health variable exhibits moderate- to high correlation with a large number of empirical health indicators.

The value-added of this paper to the existing RBC literature is the introduce a new margin of optimization: in the model, health shocks will work much like investment-specific shocks, *e.g.*, as in Greenwood *et al.* (1988), like TFP shocks. In addition, health shocks can also be viewed as demand shocks. Hansen and Wright (1992) show that disturbances affecting the demand side of the economy improve the quantitative performance of the RBC model, which extensively depends on supply (technology) shocks. Furthermore, health can have significant effect on hours: after all, fluctuations in hours are responsible for two-thirds of the fluctuation in output, the rest is due to productivity.

The rest of the paper is structured as follows: Section 2 sets up the model framework; Section 3 describes the data used and explains how the model is calibrated to the US economy; Section 4 presents the steady-state computation; Section 5 documents the impulse responses to a technology and health productivity shocks; Section 6 compares the simulated second moments of the model vis-a-vis their empirical counterparts; Section 7 discusses how the properties of the model-based variable of good health perform against empirical measures used in the development literature; Section 8 concludes.

2 Model Setup

2.1 Description of the model:

There is a representative household, as well as a representative firm. Each household owns physical capital and labor, which it supplies to the firm. Time can be spent working, exercising, being sick, or dedicated to leisure. In addition, households derive utility from health, but need to invest in it, as the stock of invisible health capital depreciates over time. The perfectly-competitive firm produces output using labor and capital. The government uses tax revenues from consumption expenditure, labor and capital income to finance lump-sum transfer payments, which are then returned to the household.

2.2 Household's Problem

As in Grossmann (2000), the household maximizes expected discounted utility

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \ln C_t^h + \psi \ln G_t^h + \theta \ln L_t^h \right\}, \tag{1}$$

where E_0 is the expectations operator as of period 0, C_t^h is consumption, G_t^h is the stock of good health, and L_t^h is leisure. The parameter β, $0 < \beta < 1$, is the discount factor. Next, $\psi > 0$ is the weight on health relative to consumption in the utility function, and $\theta > 0$ is the weight attached to leisure. The instantaneous utility function is increasing in the three arguments, concave and satisfies the Inada conditions.

The household has an endowment of one unit of time in each period t, which is then split between work, H_t^{wh}, recreation H_t^{gh}, sick time H_t^{sh}, and time off-work, L_t^h:

$$H_t^{wh} + H_t^{gh} + H_t^{sh} + L_t^h = 1. \tag{2}$$

A household that works H_t^{wh} hours generates $w_t H_t^{wh}$ of pre-tax labor income, where w_t is the hourly wage rate, and H_t^{wh} are household's hours worked.

One of the novelties in this paper is that sick time is a function of health itself, *i.e.*, $H_t^{sh} = H_t^{sh}(G_t)$. Since good health is usually linked with less days off-work due to illness, it follows that $\frac{\partial H_t^{gh}}{\partial G_t^h} < 0$. The functional form used in this paper follows Halliday *et al.*

(2009):

$$H_t^{sh} = BG_t^{-\xi}, \tag{3}$$

where $B > 0$ is a constant and $\xi > 0$ is elasticity of sick time with respect to the health status.

In addition, health depreciates over time and thus has to be maintained. The depreciation rate of health, δ^g, is to be understood as the averaged-out, time-invariant depreciation rate across the population. In addition, health can be at least partially recovered through investment in health, I_t^{gh}. The law of motion for health is as follows:

$$G_{t+1}^h = I_t^{gh} + (1 - \delta^g)G_t^h. \tag{4}$$

Replenishing health is an investment with uncertain outcome that requires time spent exercising:

$$I_t^{gh} = Z_t(H_t^{gh})^{\phi}, \tag{5}$$

where Z_t captures the uncertainty associated with the outcome of the health investment process, and $0 < \phi < 1$ is the share of time spent exercising. The range of parameter ϕ was chosen to capture decreasing returns to scale in exercise time. [1]

Finally, each household saves by investing in capital I_t^{kh}, and as an owner of capital, receives interest income $r_t K_t^h$ from renting the capital to the firm, where r_t is the return to capital and K_t^h denotes capital stock in the beginning of period t. In addition, households are owners of the firms in the economy, and receive equal share of the profit (Π_t^h) in the form of dividends. Household's physical capital evolves according to the following law of motion

$$K_{t+1}^h = I_t^{kh} + (1 - \delta^k)K_t^h, \tag{6}$$

where δ^k is the constant linear depreciation rate of physical capital.

The budget constraint for each household is

$$C_t^h + I_t^{kh} \leq (1 - \tau^k)r_t K_t^h + (1 - \tau^l)w_t H_t^{wh} + T_t^h + \Pi_t^h, \tag{7}$$

[1]Note that in the special case when $\psi = 0$, $B = 0$, $\delta^g = 0$, and $H_t^g = 0$ for all t, the model in this paper collapses to the standard RBC model.

where $0 < \tau^k, \tau^h < 1$ are the time-invariant proportional tax rates levied on capital and labor income, respectively, and T_t^h is the per-household lump-sum transfer from the government. The household acts competitively by taking prices $\{w_t, r_t\}_{t=0}^{\infty}$, and policy variables $\{\tau^k, \tau^l, T_t^h\}_{t=0}^{\infty}$ as given. It then chooses $\{C_t^h, H_t^{wh}, H_t^{gh}, H_t^{sh}, G_t^h, I_t^{kh}, K_{t+1}^h\}_{t=0}^{\infty}$ to maximize Eq. (1) subject to Eqs. (2)-(7), and initial condition for private capital and health $\{K_0^h, G_0^h\}$.

The first-order conditions (FOCs) from the household's constrained optimization problem are as follows:

$$
\begin{aligned}
C_t^h : \frac{1}{C_t} &= \lambda_t && (8)\\
K_{t+1}^h : \lambda_t &= \beta E_t \lambda_{t+1}\left[(1-\tau^k)\alpha\frac{Y_{t+1}}{K_{t+1}} + 1 - \delta\right] && (9)\\
H_t^{wh} : \frac{\theta}{1 - H_t^g - H_t^s - H_t^w} &= \lambda_t(1-\tau^l)(1-\alpha)\frac{Y_t}{H_t^w} && (10)\\
H_t^{gh} : \mu_t &= \frac{\lambda_t(1-\tau^l)(1-\alpha)\frac{Y_t}{H_t^w}}{\phi Z_t (H_t^g)^{\phi-1}} && (11)\\
G_{t+1}^h : \mu_t &= \beta\left[\frac{\psi}{G_{t+1}} + \frac{\theta B \xi G_{t+1}^{-\xi-1}}{1 - H_{t+1}^g - H_{t+1}^s - H_{t+1}^w} + \mu_{t+1}(1-\delta^g)\right] && (12)\\
\lim_{t\to\infty} \beta^t \lambda_t K_{t+1} &= 0 && (13)\\
\lim_{t\to\infty} \beta^t \mu_t G_{t+1} &= 0, && (14)
\end{aligned}
$$

where λ_t is the Lagrangian multiplier attached to the household's budget constraint, and μ_t is the corresponding Lagrangian multiplier attached to the law of motion for health. The first optimality condition equates the marginal utility of consumption with the shadow value of wealth. The second optimality condition is the Euler equation: it describes the optimal allocation of physical capital in any two adjacent periods. Hours of work are then chosen to balance the benefit of working at the margin to the cost of doing so, measured in terms of lower utility of leisure. Hours spent exercising are also determined at the point when the health gain from an additional hour is exactly offset by the the utility cost. The next dynamic optimality condition describes the inter-temporal allocation of health. Again, the household equates the benefits and costs of good health at the margin. However, the discounted benefit has three parts: first, a higher health level tomorrow brings higher utility (the direct effect); second, better health means less sick time, hence more time to work and consumption (immediate indirect effect). Thirdly, higher health means higher "undepreciated" health level and thus less replenishment is needed to get back to the old level (the inter-temporal indirect effect). The cost is that a larger replenishment was done in the previous period. The final two optimality conditions are the so-called transversality conditions (TVCs) for physical capital and health. They are imposed to rule out explosive paths for capital and health.

2.3 Firms

There is a representative firm, producing a homogeneous final product using a production function that requires physical capital, K_t and labor hours H_t^w. The production function is as follows

$$Y_t = A_t K_t^{\alpha} (H_t^w)^{1-\alpha} \tag{15}$$

where A_t measures the level of Hicks neutral technology available to the economy in period t, $0 < \alpha, (1-\alpha) < 1$ are the productivity of capital and labor, respectively.

The representative firm acts competitively by taking prices $\{w_t, r_t\}_{t=0}^{\infty}$ and policy variables $\{\tau^k, \tau^l, T_t\}_{t=0}^{\infty}$ as given. Accordingly, K_t, H_t^w are chosen optimally every period to maximize static aggregate profit,

$$\Pi_t = A_t K_t^{\alpha} (H_t^w)^{1-\alpha} - r_t K_t - w_t (H_t^w). \tag{16}$$

In equilibrium, profits are zero. In addition, labor and capital receive their marginal products, i.e

$$w_t = (1-\alpha)\frac{Y_t}{H_t^w} \tag{17}$$

$$r_t = \alpha \frac{Y_t}{K_t} \tag{18}$$

2.4 Government

Government runs a balanced budget in every period. It raises revenue by levying proportional taxes on capital and labor income. The funds collected are then returned to the public in the form of a lump-sum transfer. The government period budget constraint is thus

$$T_t = \tau^k r_t K_t + \tau^l w_t H_t^w. \tag{19}$$

Government takes market prices $\{w_t, r_t\}_{t=0}^{\infty}$, $\{H_t^w, K_t\}$ as given. Only two of the three $\{T_t, \tau^k, \tau^l\}$ policy instruments can be exogenously set. The two tax rates τ^k and τ^h will be set equal to the average effective rates in US data. The path for $\{T_t\}$ will be then residually-determined from the per-period budget balance constraint.

2.5 Stochastic processes for the policy variables

The exogenous stochastic variables are the total factor productivity A_t, and the total factor productivity of the health investment technology $\{Z_t\}$. Then assume that A_t, Z_t follow AR(1) processes in logs, in particular:

$$\ln A_{t+1} = (1 - \rho^a) \ln A_0 + \rho^a \ln A_t + \epsilon_{t+1}^a, \tag{20}$$

where $A_0 > 0$ is steady-state level of the total factor productivity process, $0 < \rho^a < 1$ is the first-order autoregressive persistence parameter and $\epsilon_t^a \sim iidN(0, \sigma_a^2)$ are random shocks to the total factor productivity progress.

The process for health investment total factor productivity $\{Z_t\}$ is

$$\ln Z_{t+1} = (1 - \rho^z) Z + \rho^z \ln Z_t + \epsilon_t^z \tag{21}$$

where $Z > 0$ is steady-state level of technology, $0 < \rho^z < 1$ is the first-order autoregressive persistence parameter and $\epsilon_t^z \sim iidN(0, \sigma_z^2)$ are random shocks to total factor productivity in health investment.

2.6 Decentralized Competitive Equilibrium

Given the paths of the policy instrument $\{T_t\}_{t=0}^{\infty}$, the exogenous process followed by $\{A_t, Z_t\}_{t=0}^{\infty}$ and initial conditions for the state variables $\{K_0^h, G_0^h\}$, a decentralized competitive equilibrium (DCE) is defined to be a sequence of allocations $\{C_t^h, G_t^h, H_t^{wh}, H_t^{gh}, H_t^{sh}, I_t^{kh}, K_{t+1}^h\}_{t=0}^{\infty}$ $\forall h$, prices $\{r_t, w_t\}_{t=0}^{\infty}$ and the tax rates $\{\tau^k, \tau^l\}$ such that (i) households maximize utility; (ii) firms maximize profits; (iii) all markets clear and (iv) the government budget constraint is satisfied in each time period.

3 Calibration and Data

The model is calibrated to US data at quarterly frequency. The period under investigation is 1948:1-2009:4, where the cut-off was made to isolate the effect of the financial crisis. The chapter follows the methodology used in Kydland and Prescott (1982), as it is the standard approach in the literature. Both the data set and steady-state DCE relationships of the models will be used to set the parameter values, in order to replicate relevant long-run moments of the US economy for the period discussed. Quarterly data on real output (measured in constant 2005 dollars), household consumption, private fixed investment, shares in output, total hours, wages and productivity were obtained from the Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS). The health status series was obtained from the World Health Organization (WHO) Database.

The discount factor $\beta = 0.995$ was calibrated from the household's Euler equation.[2] Next, the relative weight attached to health, ψ, was obtained as follows: since health care spending share in the US basket is 6.3 % (1.57 % for medical care commodities and 4.73 % for medical care services), and household's non-durable consumption spending takes 30.2 % of output, when we normalize, we obtain $\psi = 6.3/30.2 = 0.209$. Next, the relative weight on leisure, parameter $\theta = 1.453$, was calibrated so that in steady-state the household will work $h^w = 1/3$. The tax rates on labor and capital, $\tau^l = 0.25$, and $\tau^k = 0.43$, respectively, were set equal to their average effective rates in the US data. The share of labor in total income, $1 - \alpha = 2/3$ was obtained as an average share of total wage bill in GDP. The linear depreciation rate of physical capital is set to $\delta^k = 0.02$, which is a typical value used in the literature (e.g. Kydland and Prescott 1982). For health, a constant depreciation rate $\delta^g = 0.02$, is assumed for easier model tractability, and is an adequate approximation when discussing overall health of a nation.

Steady-state sick days, $h^s = 0.02$, are calculated from data on US taken from CES-Ifo DICE Database (2013). Elasticity parameter $\xi = 1.340$, was estimated from a cross-section regression on the logged series of total sick days on the logged proportion of people self-

[2] Alternatively, the discount factor could be set to match the after-tax, net of depreciation return to equity during the period.

reported to be in good health. The estimate is close to the calibration value $\xi = 1.5$ used in Halliday *et al.* (2009). We impose the steady-state relationship between sick hours and health and obtain $B = 0.07$. The value of hours in health production function, h^g, was then chosen to match the share of time spent doing sports and engaging in recreational activities (for those who exercise) in the ASUS data. In steady state $h^g = 0.02$, or half an hour on average. Productivity of hours in health production, $\phi = 0.927$, was set as unity minus the average share of health expenditures in the government budget. Thus, investment in health technology would feature mild decreasing returns to scale in exercise hours.

The steady-state levels for total factor productivity, A, and health investment productivity, Z, are normalized to unity. The values of those two parameters have only a level effect in the model, so their magnitudes are irrelevant. Finally, the parameters of the Z_t shock process will be estimated from an AR(1) regression, thus obtaining a persistence coefficient $\hat{\rho}_z = 0.69$ and standard deviation $\hat{\sigma}_z^2 = 0.025$. Identical steps were followed in the estimation of total factor productivity moments from the Solow residual, producing a persistence estimate of $\hat{\rho}_a = 0.9$ and a standard deviation of $\hat{\sigma}_a = 0.007$. Table 1 on the next page summarizes the values of all model parameters, and the next section provides the computed values of the model variables in the steady-state.

Table 1: Model Parameters

Parameter	Value	Method	
β	0.995	discount factor	Calibrated
α	0.333	Productivity of capital	Data average
ψ	0.209	Relative weight on utility from health	Set
θ	1.453	Relative weight on utility from leisure	Calibrated
δ^k	0.0250	Depreciation rate of physical capital	Data average
δ^g	0.020	Depreciation rate of health	Data average
ξ	1.500	Elasticity of sick time to health	Estimated
ϕ	0.927	Productivity of hours spent exercising	Data average
A	1.000	Steady-state level of technology	Set/Calibrated
B	0.070	Scale factor of sick time	Calibrated
Z	1.000	steady-state level of health shock	Set/Calibrated
τ^k	0.430	Effective average tax rate on capital income	Data average
τ^l	0.250	Effective average tax rate on labor income	Data average
ρ^a	0.900	AR(1) parameter, total factor productivity	Estimated
ρ^z	0.690	AR(1) parameter, health investment productivity	Estimated
σ_a	0.007	st. dev., total factor productivity	Estimated
σ_z	0.045	st. dev., health investment productivity	Estimated

4 Steady-State

Once model parameters were obtained, the steady-state ratios for the model calibrated to Bulgarian data were obtained. The results are reported in Table 2 below.

Table 2: Data Averages and Long-run solution

	Description	US Data	Model
c/y	Consumption-to-output ratio	0.647	0.870
i/y	Fixed investment-to-output ratio	0.160	0.130
k/y	Physical capital-to-output ratio	6.400	6.400
$w\bar{h}^w/y$	Labor share in output	0.667	0.667
rk/y	Capital share in output	0.333	0.333
h^w	Share of time spent working	0.333	0.333
h^s	Share of time spent sick	0.020	0.020
h^g	Share of time spent exercising	0.020	0.020
$\tilde{r}$	After-tax net return to physical capital	0.004	0.004

As seen from the tabulated values, the model captures relatively well the investment ratio. The model slightly overestimates the consumption-to-output ratio because it includes government consumption as well. In addition, the parsimonious model does a relatively good job at matching the after-tax net return on capital, where $\tilde{r} = (1 - \tau^k)r - \delta^k$. In the following subsection, the model dynamics around the steady-state will be investigated: first, the impulse responses to shocks to technology and health will be presented, and then the simulated second moments of the model will be compared and contrasted to their empirical counterparts.

5 Model Solution and Impulse Responses

Since the models of this class do not have a closed-form solution, the non-linear system of equations describing the DCE will have to be solved numerically through a linearization procedure. The obtained linear system from this approximation can be represented in the form of first-order linear stochastic difference equations as in King, Plosser and Rebello

(1988):

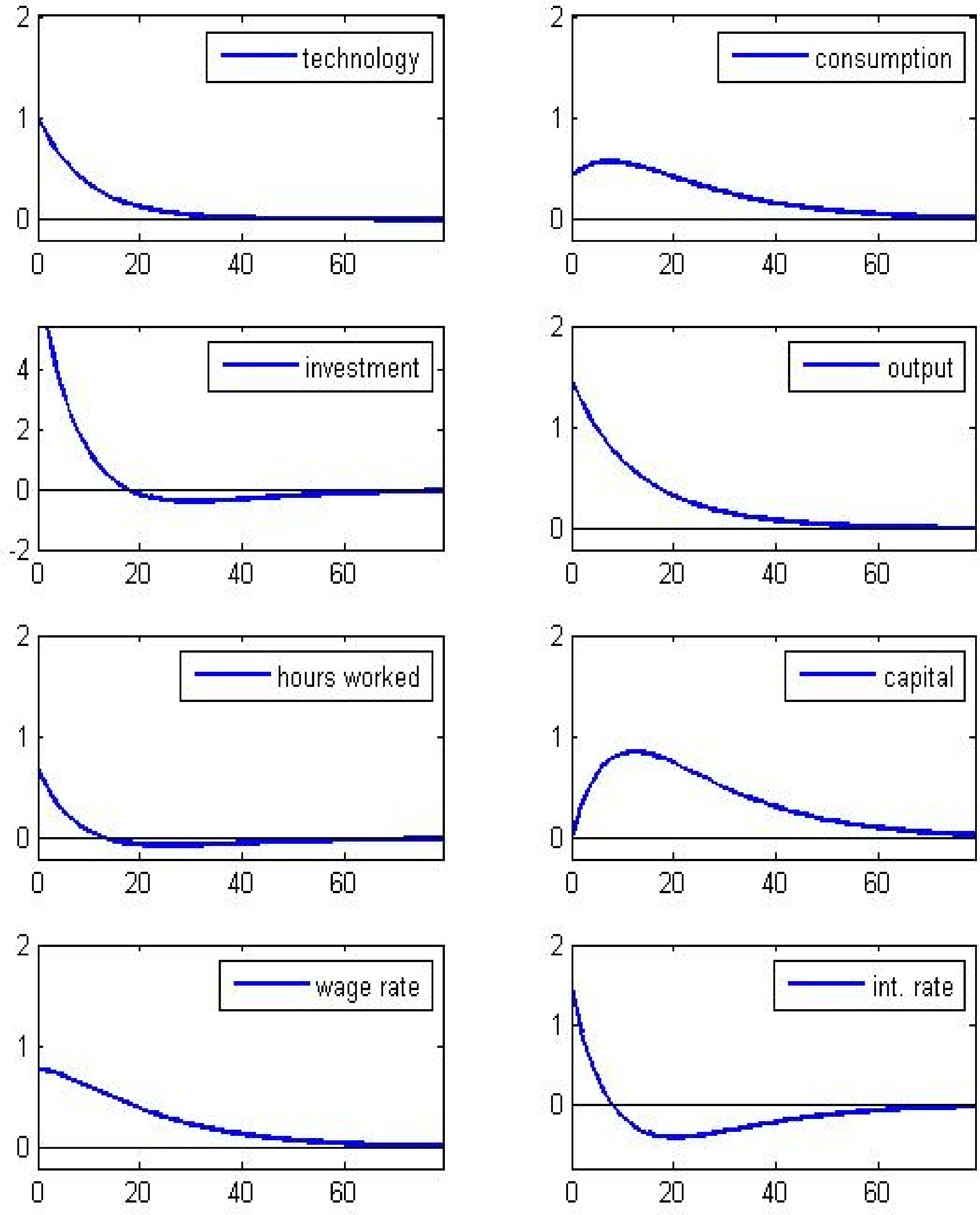
$$\mathbf{A}E_{t+1}\hat{\mathbf{x}}_{\mathbf{t}} = \mathbf{B}\hat{\mathbf{x}}_{\mathbf{t}} + \epsilon_{\mathbf{t}} \quad (22)$$

where $\mathbf{A}, \mathbf{B}$ are coefficient matrices, $\epsilon_{\mathbf{t}}$ is a matrix of innovations, and $\hat{\mathbf{x}}_{\mathbf{t}}$ is the stacked vector of state (also called 'predetermined') variables, $\hat{\mathbf{s}}_{\mathbf{t}}$, and control (or "choice") variables, $\hat{\mathbf{z}}_{\mathbf{t}}$. Klein's (2000) generalized eigenvalue decomposition algorithm was used to solve the model. Using the model solution, the impulse response functions (IRFs) were computed to analyze the transitional dynamics of model variables to (i) a surprise innovation to either total factor productivity (TFP) productivity, and (ii) a surprise innovation to health investment productivity, with a particular attention being paid on the behavior of health variables.

5.1 The Effect of a positive productivity shock

Figures 1 and 2 on the following pages show the impact of a 1 percentage point surprise TFP innovation on the economy with health valued by the household and health investment. The impulse responses are expressed in log-deviation from the variables' original steady-states in the model economy calibrated to quarterly US data. There are several main channels through which the TFP shock affects the model economy. First, a higher TFP increases output directly upon impact. This constitutes a positive wealth effect, as there is a higher availability of final goods, which could be used for private and public consumption, as well as investment. Meanwhile, the positive TFP shock increases both the marginal product of capital and labor, hence the real interest rate and the wage rate increase. The household responds to the price signals and supplies more hours worked, as well as increasing investment level. This increase in labor supply and capital accumulation is also driven from both the inter-temporal consumption smoothing and the intra-temporal substitution between private consumption and leisure. In terms of the labor-leisure trade-off, the income effect ("work more") produced by the increase in the private wage dominates the substitution effect ("work less"). Furthermore, the increase of hours worked expands output even further, and thus upon impact of the technology shock output increases by more than the size of the shock. Over time, as physical capital stock accumulates, marginal product of capital falls, which slowly decreases the incentive to invest. Given that capital and labor are complements in the Cobb-Douglas production function, wage rate will also reach a peak and then return to

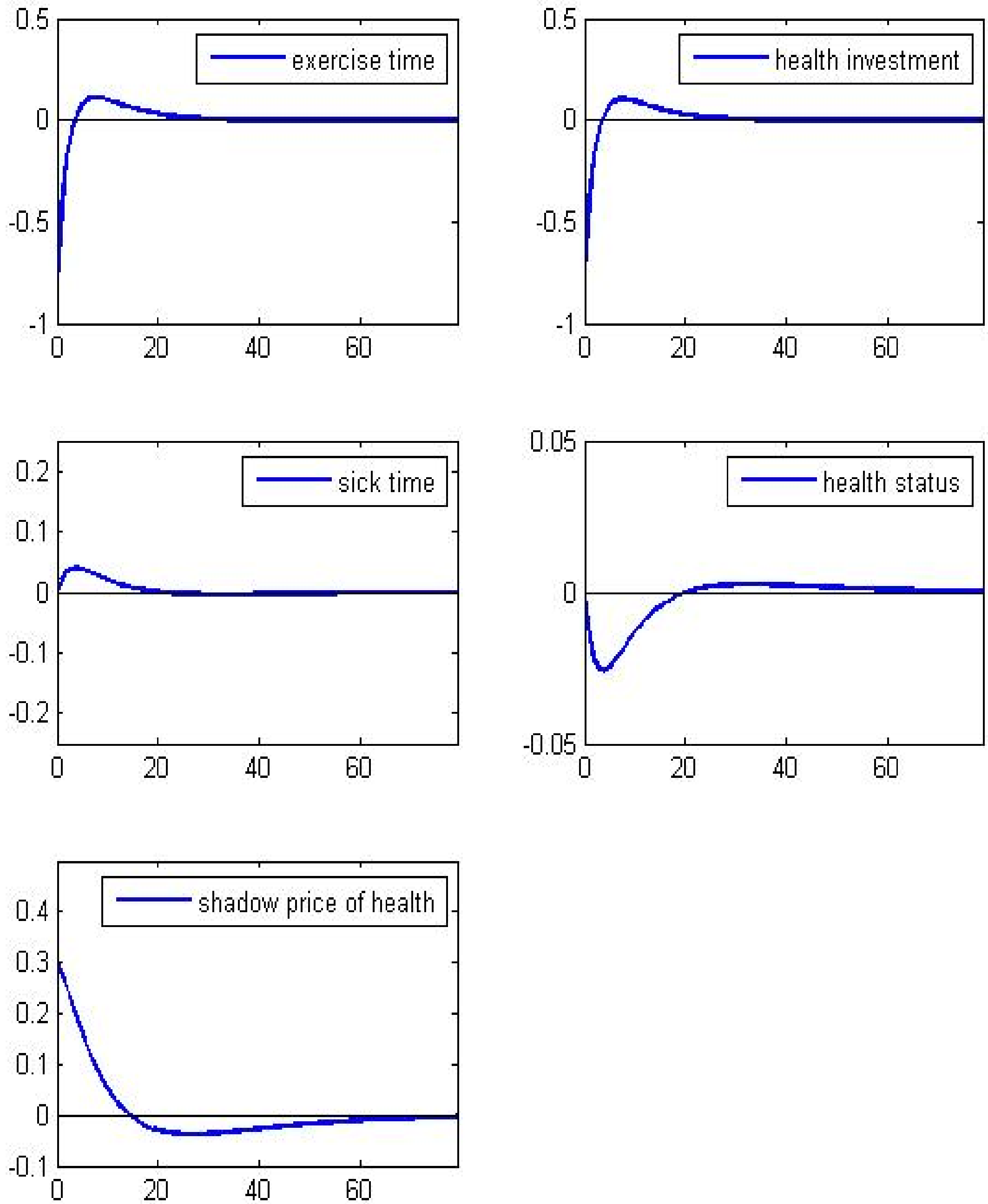
Figure 1: Impulse Response Functions to a 1 percentage point innovation to technology



its old steady-state level as the technology shock starts to die out. Finally, consumption (being the sum of after-tax labor and capital income) would also inherit the hump-shaped dynamics of physical capital behavior: Upon impact of the technology shock it jumps, then smoothly increases until it peaks, after which it gradually returns to its initial steady-state.

The new dimensions of adjustment in this economy, the dynamics of the health variables works as follows: Given the positive effect of the technology shock on the labor supply, there is a decrease in the number of hours spent exercising upon the impact of the shock. This is driven by the perfect substitutability of hours in the utility of leisure. As the marginal productivity of labor, and thus the wage rate decrease, labor hours are redirected from working to exercising. Exercise time increases, reaches a peak, and then returns to its steady-state level. Next, since health investment is a deterministic concave function of exercise hours, investment in health will mimic the dynamics of hours exercising. Overall health status will follow the dynamics of health investment, but only with a lag, given the high persistence describing health accumulation. The shadow price of health is proportional to the wage rate, and thus follows its dynamic as well. Lastly, sick days will be the mirror image of health, due to the stable negative relationship between the two variables. In the long-run, all variables return to their old steady-state values. Due to the highly-persistent TFP process, the effect of the shock is still present after 70 periods (quarters). Next, the effect of an innovation in health investment productivity on model variables is illustrated and discussed in the following subsection. Similarly to the case with the technology shock, the focus is again on the behavior of the health-related variables.

Figure 2: Impulse Response Functions to a 1 percentage point innovation to technology (cont'd)



5.2 The Effect of a positive health investment shock

Figures 3 and 4 on the following pages show the impact of a 1 percentage point unanticipated innovation in health investment productivity on the economy. Again, the impulse responses are expressed in log-deviation from the variables' original steady-states in the model economy calibrated to quarterly US data. The new propagation mechanism is the stochastic productivity differential between the marginal product of labor in the market versus the productivity of an extra hour used in the health investment function. However, the quantitative effects of disturbances in health investment productivity are not large, due to the low persistence of the shock process, approximately twice lower than the technology shock. The effect of the health investment shock has effectively disappeared after only 10-15 periods (quarters). Thus, health shocks by themselves alone are unlikely candidate for major drivers of business cycle fluctuations.

Upon the impact of the shock, the immediate return to health investment, measured in terms of the marginal product of an additional hour of exercise, is now higher, and since the shock is short-lived, hours spent exercising respond a lot initially, then undershoot and eventually return to their old steady-state. As a result of the substantial increase in exercise time, health investment, as well as health status, initially increase, reach a peak and then gradually return to their steady-state value; just the opposite happens with the behavior of sick days. In addition, as supply of health increases, its shadow price falls, reaches a through, and then returns from below to its steady-state value.

Next, since all three types of hours (hours worked, exercise hours, and sick time) are perfect substitutes, hours of work decrease when more time is dedicated to exercising. As a result of that reallocation of labor resources away from output production, the marginal productivity of capital falls as well. This follows from the complementarity between capital and labor in the Cobb-Douglas production function. In turn, less after-tax labor and capital income is generated. The effect on total net income is quantitatively small though. Therefore, we can consider that aggregate output and consumption effectively remain unchanged, despite the tiny drop upon impact of the health shock, mostly due to the household re-balancing its optimal choice towards higher health status. Investment response is also very similar to

Figure 3: Impulse Response Functions to a 1 percentage point shock to health investment

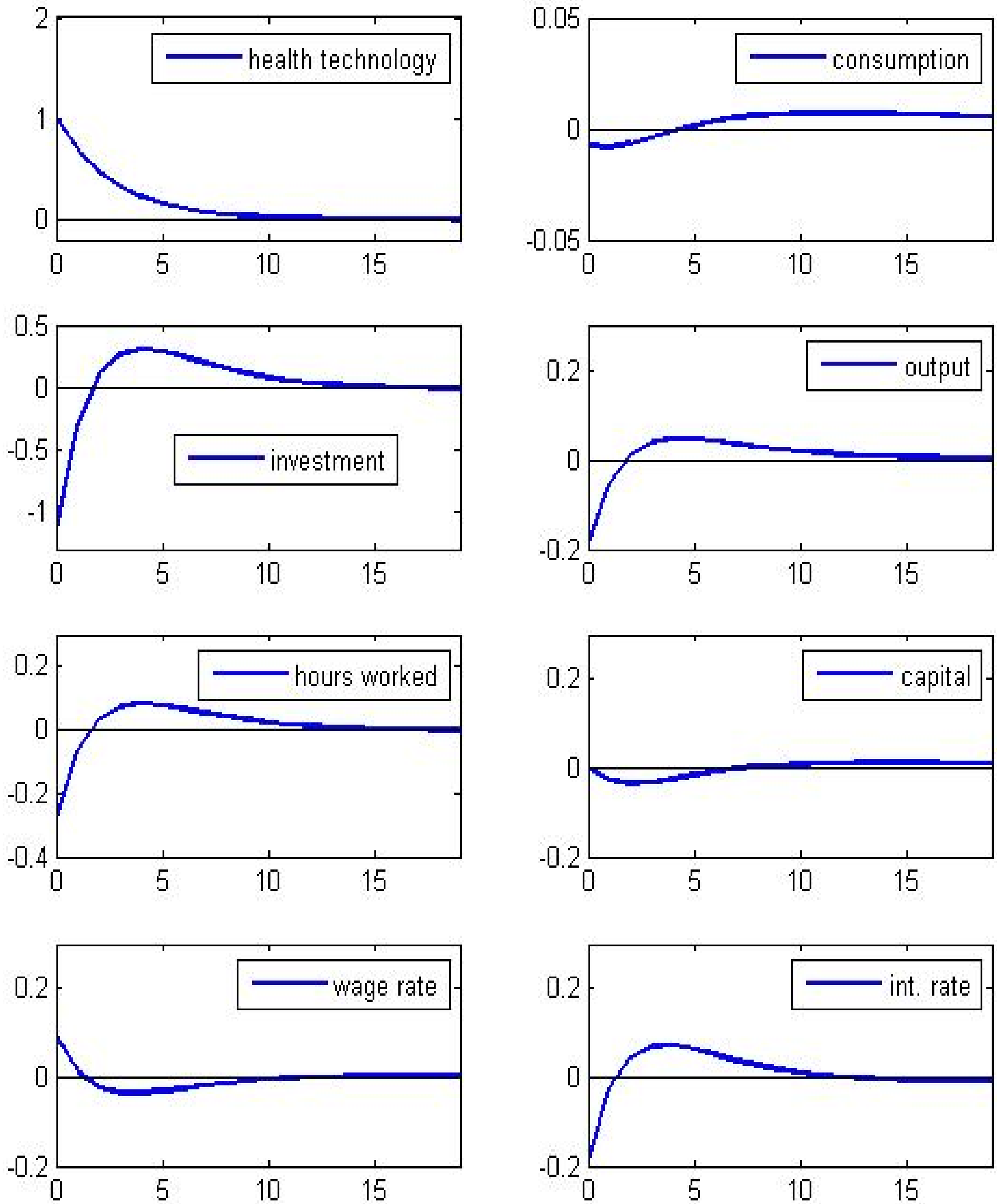
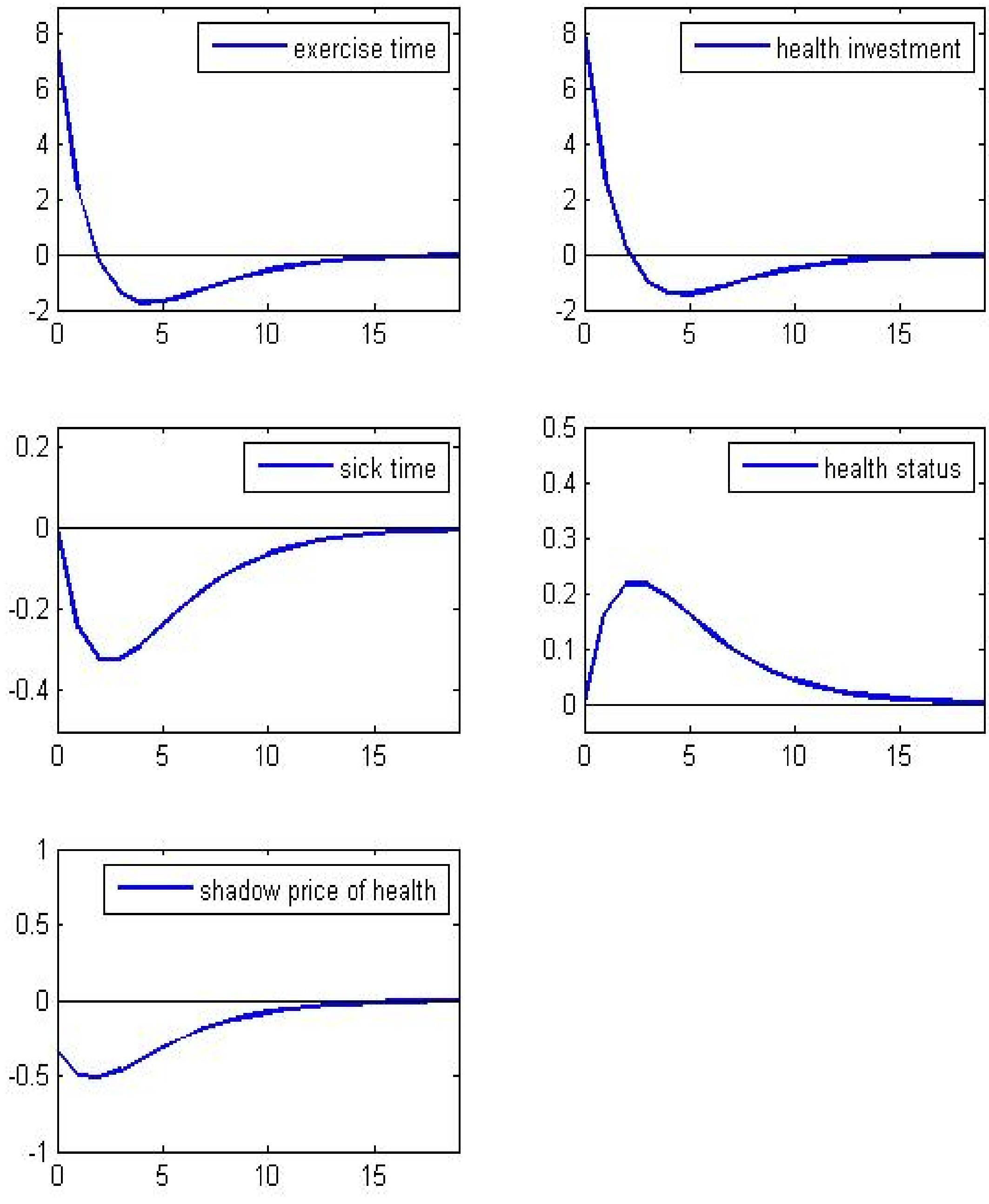


Figure 4: Impulse Response Functions to a 1 percentage point shock to health investment (cont'd)



the behavior of consumption, output and hours worked, but the drop is more pronounced since this component of spending is the most volatile compared to the variability of other aggregate variables. Over time, due to the scarcity of physical capital, interest rate increases, investment and hours worked recover, and then slowly return to their old steady-state levels, following a hump-shaped pattern. However, the adjustment of the variables in the economy after an unexpected shock is rather quick. This is mainly due to the low persistence of the health investment shock. Its impact of an unanticipated health investment innovation has virtually disappeared after only 10-15 periods (quarters).

6 Model Simulation and Moments evaluation

Using the model solutions, shock series were added to produce simulated data series. The length of the draws for the series of innovations is 228, corresponding to the length of the quarterly US data, and the simulation is replicated 1000 times. Natural logarithms are taken, and then all series are run through the Hodrick-Prescott filter , with a smoothing parameter for quarterly series equal to 1600. Then the first 100 observations are excluded to decrease any influence of initial conditions. To minimize sample error, average standard deviation of each variable and its correlation of output of are estimated across the 1000 replications. The theoretical second moments of the simulated data series are then compared against their empirical counterparts. Table 3 on the next page reports the empirical and simulated moments for the US economy. US data is compared against the specification with both shocks, as well as the special cases with technology- and health shocks only, respectively.

In the US data, relative consumption volatility is less than one. Since a major force in the model is consumption smoothing, as dictated by the Euler equation, all three models predict quite closely consumption volatility and investment variability. In both models with technology shocks, private sector hours vary less than data, while wage volatility is captured well by a model featuring shocks to technology. The relative volatility of hours to wages is underestimated by the data, but health shocks alone show some promise of fixing that deficiency. Furthermore, it is a well-known fact (e.g. Hansen 1992) that the standard RBC model captures private sector labor market dynamics only imperfectly.

Table 3: Model Evaluation

	US Data 1947:1-2008:4	Model (both shocks)	Technology shocks only	Health investment shocks only
σ_c/σ_y	0.69	0.76	0.75	0.47
σ_i/σ_y	2.97	3.10	3.13	4.54
σ_{h_w}/σ_y	0.85	0.28	0.28	1.35
σ_w/σ_y	0.81	0.83	0.83	0.52
σ_{h_w}/σ_w	1.05	0.34	0.34	2.61
$corr(c, y)$	0.61	0.91	0.91	0.80
$corr(i, y)$	0.75	0.84	0.85	0.94
$corr(h_w, y)$	0.82	0.69	0.70	0.95
$corr(w, y)$	0.59	0.97	0.97	-0.54
$corr(h_w, y/h)$	-0.08	0.69	0.50	-0.78
σ_g/σ_y	0.43	1.18	1.17	0.97
$corr(g, y)$	0.62	0.78	0.77	0.43
σ_μ/σ_y	1.88	0.52	0.15	4.98
$corr(\mu, y)$	-0.45	0.15	0.73	-0.38
$\sigma_g/\sigma_{y/h}$	0.81	1.42	1.41	1.88
$corr(g, y/h)$	0.08	0.91	0.91	0.51

Next, all specifications capture the high contemporaneous correlations of main variables with output relatively well. It is evident from Table 3 on the previous page that the model with technology shocks overestimates the hours-wage correlation, but the result is nevertheless a significant improvement from the perfect negative relation predicted by the benchmark RBC model. In the model with health investment, the additional margin for hours allocation, together with the productivity differential triggers a relocation of hours between hours worked and hours exercising due to the perfect substitutability of hours in the utility of leisure. This effect breaks the co-movement of working hours and productivity.

Finally, all three models specifications capture quite well the correlation of health with output, but substantially overestimate the relative volatility of health. However, the model does a relatively adequate job with the behavior of price of health care as approximated by the shadow value of health in the model. Interestingly, in the US data, health is not related to productivity, while the model predicts a strong correlation. Again, health shocks have some potential accounting for that, as a model with health investment disturbances lowers the positive co-movement between health and productivity in the model.

Overall, the model with the health investment captures adequately US data, addressing dimensions that were ignored in earlier RBC models. Thus, health considerations in the utility function (both directly and indirectly through its effect on sick days), and modelling health dynamics as a health capital accumulation process proves to be an important ingredient in RBC models. To assess the relevance of the model-based measure of health for empirical health dynamics, several health indicators are compared to the simulated series.

7 Model-based health measure vs. empirical health indicators

In this section we compare how the model-generated health series compares to empirical measures of health. The simulated health series is first averaged over the simulations in order to minimize sample error and annualized. The correlations are provided in Table 4 on the next page. The model-based measure of good health compares quite well against the life-expectancy-at-birth statistic, both in total terms and for males separately (but not so well for females). The simulated good health measure is also strongly and negatively correlated with two alternative measures used in health literature, the mortality rate and the potential years of life lost (PYLL), again presented separately for males and females. Similar moderate negative relationship is observed also with suicide rate indicator, and cancer mortality rates (cancer being one of the top reason for deaths in the US). Finally, the vaccination rate against measles and especially the combined DPT (Diphtheria, Pertussis, a.k.a. ”whooping cough”, and Tetanus) treatment are significantly positively correlated with the model-based measure of good health. This is in line with studies showing that the community immunity from vaccinating whole populations has effectively eradicated many dangerous diseases which were responsible for a lot of deaths in the past.

Table 4: Correlation with health indicators (time series)

Life Expectancy at Birth, Total	0.4
Life Expectancy at Birth, Male	0.51
Life Expectancy at Birth, Female	0.05
Adult mort rate male	-0.58
Adult mort. rate, female	-0.71
Potential Years of Life Lost(PYLL) males	-0.63
Potential Years of Life Lost(PYLL) females	-0.35
Suicide rate	-0.38
Cancer mort. rate males	-0.41
Cancer mort. rate females	-0.19
Cancer mort. rate	-0.31
Vaccination Rate Measles	0.29
Vaccination Rate DPT	0.42

Next, in addition to time-series measures, the simulated health measure was compared in a cross-section with data on the US, Finland, Netherlands, and Japan. The correlations are documented in Table 5 on the next page. Again, despite its simplicity and subjectivity, this measure of health of a nation is again highly correlated individually with factors such as male life expectancy at 65, the male stroke rate, suicide rates, and people undergoing dialysis. The good health measure is negatively correlated with indicators such as the percentage of the population smoking daily, liver diseases and cirrhosis, and low birth weight. The picture is similar for the ischemic heart diseases, the stroke rate mortality rate, and cancers: Cervical cancers are among the leading cause of death for females in the US, while for males that is the colorectal cancer. The number of missing teeth seems also a good measure of problems with internal organs. Flu vaccination of elderly people seems quite important, as the prevailing causes of death among elderly are "complications from common cold" (OECD 2009).

Table 5: Correlation of the good health measure (cross-section) with

Percentage of adult population smoking daily	-0.31
Liver diseases and Cirrhosis	-0.61
Suicide	-0.37
Male Life Expectancy at 65	0.57
Female Life Expectancy at 65	0.28
Male Life Expectancy at birth	0.54
Female Life Expectancy at birth	0.18
Low birth weight	-0.21
Male stroke mortality rate	-0.76
Female stroke mortality rate	-0.63
Lung cancer mortality rate	-0.31
Male Cancer mortality rate	-0.47
Cervical Cancer Mortality	-0.42
Colorectal Cancer Mortality	-0.29
Male Ischemic heart disease mortality rate	-0.26
Female Ischemic heart disease mortality rate	-0.33
Prevalence of patients undergoing dialysis	-0.45
Number of missing and damaged teeth	-0.54
Flu vaccination of elderly people	0.47
Measles vaccination	-0.42
Potential Years of Life Lost male	-0.48
Potential Years of Life Lost female	-0.21

8 Conclusion

This paper attempted to shed light on the importance of overall health status as a source of business cycle fluctuations and its effect on the labor productivity and availability of labor input for productive use. To this end, Grossmans (2000) partial-equilibrium framework with endogenous health was incorporated in an otherwise standard RBC model. Health status in this setup was modelled as a utility-enhancing, intangible, and non-transferrable capital stock, which depreciates over time. Households in the model could improve their health through exercise, vacation time, a good diet, and recreation. However, investment in health produced an uncertain outcome because it was subject to health-specific shocks. The main results from the study are: (i) overall, the model compared well vis-a-vis data; (ii) the behavior of the price of health-care was adequately approximated by the shadow price of health in the model; (iii) the model-generated health variable exhibited moderate- to high correlation with empirical measures of health.

As a possible venue for future research, an optimal fiscal policy exercise could be considered. In particular, optimal spending on health care could be computed. After all, public spending on health is the second-largest government program (after education). Model-wise, medical care could be included as a second productive input in the production of health. However, in the exogenous policy case (health care modelled as a stochastic process), its effect will not be qualitatively different from the effect of the productivity of the health investment process. Alternatively, the model could try to differentiate between chronic and acute diseases, where the former could decrease a worker's capacity permanently, while the latter are only temporary, and model those appropriately. However, all there potential extensions of the model are left for future work.

References

ATUS (2009). *American Time Use Survey*, Bureau of Labor Statistics. Available on-line at www.bls.gov/tus/.

BEA (2009). *Bureau of Economic Analysis Statistics*. Available on-line at www.bea.gov.

BLS (2009). *Bureau of Labor Statistics*. Available on-line at www.bls.gov.

DICE (2011). *CES-Ifo DICE Database*. Available on-line at www.cesifo-group.de.

Greenwood, J., Hercowitz, Z., and Huffman, G. W. (1988). "Investment, Capacity Utilization, and the Real Business Cycle," *American Economic Review*, vol. 78(3), pages 402-17, June.

Grossman, M. (2000) "The Human capital Model of the Demand for Health," *Handbook of Health Economics*.

Grossman, M. (1972) "On the concept of health capital and the demand for Health," *Journal of Political Economy*, 80:223-255.

Halliday, T., He, H., and Zhang, H. (2009) "Health Investment over the Life Cycle." *IZA WP* 4482.

Hansen, G., and Wright, R. (1992) "The labor market in real business cycle theory," *Quarterly Review of the Federal Reserve Bank of Minneapolis*, pp. 2-12 (Spring).

Hodrick, Robert; Prescott, Edward C. (1997). "Postwar U.S. Business Cycles: An Empirical Investigation". *Journal of Money, Credit, and Banking* 29 (1): 1-16.

King, R., Plosser, C., and Rebelo, S. (1988) "Production, Growth and Business Cycles I. The Basic Neoclassical Model," *Journal of Monetary Economics* 21: 195-232.

Klein, P. (2000) "Using the generalized Schur form to solve a multivariate linear rational expectations model," *Journal of Economic Dynamics and Control*, vol. 24(10), pp. 1405-1423, September.

Kydland, Finn E, and Prescott, E. C, 1982. "Time to Build and Aggregate Fluctuations," *Econometrica*, vol. 50(6), pp. 1345-70, November.

OECD (2009). *Health at a Glance*. OECD: Paris, France.

Prescott, E. C. (1998) "Needed: A theory of Total Factor Productivity," *International Economic Review*, vol. 39(3), pp. 525-51.

WHO (2010). *World Health Organization: Health for All Database*. Available on-line at: www.who.int/en/.

Zweifel, P., Breyer, F., and Kifmann, M. (2009) *Health Economics*, 2^{nd} *ed.* Springer: Berlin, Germany.