Central Bank of Armenia

Working Paper

Modeling the Effects of Health Shock on Economy: Standard NK DSGE Framework

Ani Asoyan
Vahagn Davtyan
Haykaz Igityan
Hasmik Kartashyan
Hovhannes Manukyan

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CBA Working Paper

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Abstract

As coronavirus (COVID-19) spreads throughout the world, epidemiological (SIR) models are widely being used for research. Indeed, these models are very useful for modeling the spread of virus, but they do not take into account the behavior of economic agents operating in the economy. This paper extends closed economy DSGE model in order to evaluate the impact of coronavirus on the economy. Our model makes clear that people's decisions to reduce consumption and working hours due to health crisis leads to economic recession. As a result, spread of virus declines. Expansionary monetary policy decreases the size of GDP decline, but it is costly in terms of health. This result shows that there is a trade-off between the output loss caused by the epidemic and the health consequences of that epidemic.

JEL classification: E12, E52, I10
Keywords: DSGE, Health, Epidemic, COVID-19

The views expressed in this paper are those of the authors and do not necessarily represent the views or policies of the Central Bank of Armenia.

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1 Introduction

The latest pandemic shock stimulate to modify standard DSGE models by incorporating into it health block and linking epidemiology models, which can allow to understand the repercussions of the pandemic shock on the whole economy. There are several papers in the literature, which analyze the pandemic shock and the transmission of this shock.

Eichenbaum et al. (2020) extend the canonical epidemiology model to study the interaction between economic decisions and epidemics. Their model implies that people's decision to cut back on consumption and work reduces the severity of the epidemic, as measured by total deaths. Moreover, containment policy, represented by tax on consumption, deepens the economic crisis, but reduces the number of infected and deaths. Their results indicate the presence of trade-off between GDP and the number of deaths.

Kruger et al. (2020) use Eichenbaum's model by composing several heterogeneous sectors that are differentiated by infection probabilities. They assume that consumption of goods can be shifted from market place to home. Likewise remote work can replace office work. High flexibility of consumption and labor supply among sectors decreases the spread of infection and mitigates loss in consumption. By introducing additional social distancing and hygiene activities, they show that infection declines entirely and the curve gets reversed. The main idea is that in flexible economy with high substitution of consumption across sectors and smoothly functioning labor markets, health shocks are less costly and economy quickly adapts to changes.

Acemoglu et al. (2020) develop multi-risk SIR model (MR-SIR) with 3 age groups: "young", "middle-aged" and "old". Infection and fatality rates vary across these groups. The result is that in contrast to uniform lockdowns which treats all the groups equally, applied targeted policies to a particular group do a better performance in terms of both economic and health outcomes. During optimal targeted policies, it is possible to decrease fatality rate given output loss and vice versa. Semi targeting policies that involve strict lockdown of elders and allow other groups to be economically active, achieve lower fatality rate compared to uniform policy and reduces economic damage. Combined targeted policies that decrease interactions between groups, also outperform uniform policy and significantly reduce fatality rate and mitigate economic damage. Furthermore, combining targeted policies with different tools such as social distancing between groups, testing and isolation can improve trade-off between economic activity and public health.

Adda (2015) using high frequency data from France finds that while policies reducing inter-personal contacts such as school closure or the closure of public transportation networks reduce disease prevalence, they are not cost-effective. These policies would become cost effective for flu epidemics in instances when their death rate is above average.

Torój (2013) attempts to apply a New Keynesian open economy model to simulate the economic consequences of influenza epidemic in Poland and measure the output loss (indirect cost) related to disease. The simulated indirect cost in the New Keynesian model has turned out to be lower than the estimates that one could possibly obtain using the human capital approach. The reason for this discrepancy is the demand-oriented construction of the New Keynesian framework.

This paper aims to model the healthcare sector in the propagation of the pandemic shock and attempt to find out the effects of Covid-19 spread on economic decisions. In this framework the role of monetary policy is also important as the coherent policy during pandemic outbreak is a significant issue, that policymakers are concerned about. In our model we consider standard New Keynsian dynamic stochastic general equilibrium model (NK DSGE) for closed economy extended by incorporating health block into it. There are three main agents: households, firms and central bank. The representative household consumes health and non-health goods, represents labor supply and do investment for capital accumulation, which is divided into health capital and physical capital accumulation. Firms are divided into two sectors: health sector and other sector. They use effective capital and effective labor to produce consumer goods. It should be noted, that the effectiveness of labor is measured by the stock of the health capital. Model highlights that expansionary monetary policy during the pandemic shock, in spite of the fact that it is stimulate the economy in the short-run, promotes health stock to maintain lower level in that period.

The rest of the paper is organized as follows. Second section develops and describes two-sector DSGE model. Third section illustrates the calibration of the parameters. Section four performs the main results of the model, representing dynamics of the main economic variables in response to the health and monetary policy shocks and sensitivity analysis for studying which parameters mostly drive the health stock and the main economic variables. Finally, section five concludes.

2 The Model

This section develops standard set of microfoundations in a DSGE model, allowing to take into account health and its economic implications. The basic structure of the model is as follows. Households receive utility from non-health goods consumption, from leisure and from being healthy. Health status is introduced within the household utility function à la Yagihashi and Du (2016), and it indicates the health stock accumulation. The representative household works in health and non-health sectors, consumes goods, which are divided into health and non-health goods, investment in health and non-health capital accumulation. Households solve two optimization problems. Firstly, they minimize their total expenditures and decide how much consume health and non-health goods. Secondly, they maximize their utility function subject to the budget constraints, which states that all sources of income must equal all uses of income within each period. Households are assumed to own all factors of production in the economy (capital and labor in our model). They also hold some amount of government bonds that pay a nominal riskless interest rate. Households also choose the utilization rate of capital and supply it to domestic firms producing intermediate goods. Firms in non-health production sector uses labor and capital resources to produce non-health consumption goods. Health sector producers use the same resources to produce health consumption goods and isolation. The intermediate good producers in each sector use Cobb-Douglas production function. The monetary authority sets the nominal interest rate via Taylor rule. The schematic representation of the model is captured in figure 1.

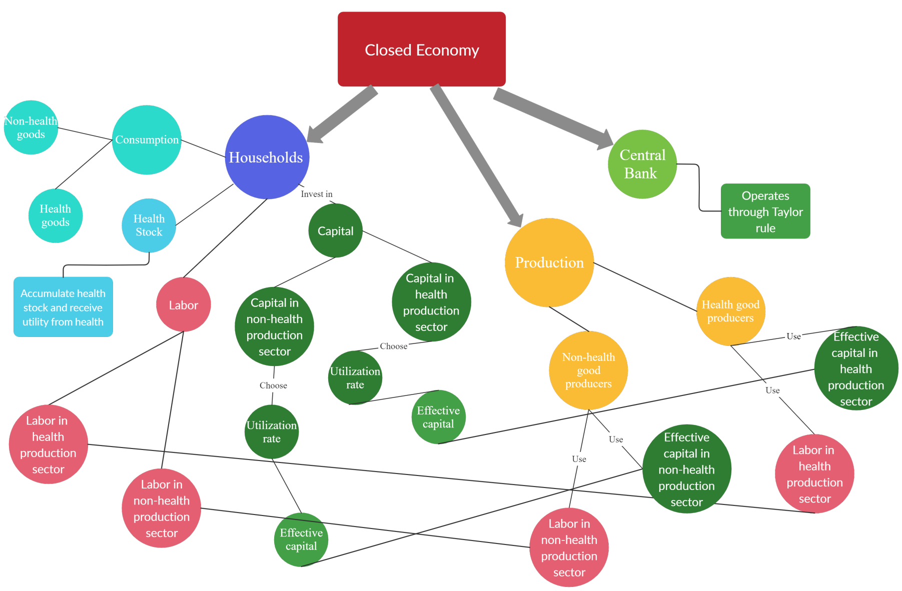


Figure 1: Model Environment

2.1 Households

The household seeks to maximize the following utility function

$$E_t \sum_{j=0}^{\infty} \beta^j \left(\frac{C_{N,t+j}^{1-\sigma}}{1-\sigma} - \chi_N \frac{N_{N,t+j}^{1+\varphi_N}}{1+\varphi_N} - \chi_H \frac{N_{H,t+j}^{1+\varphi_H}}{1+\varphi_H} + \psi \frac{H_{t+j}^{1-\eta}}{1-\eta} \right) \tag{2.1.1}$$

where E_t is the expectation operator condition on information available at time t, β is the discount factor, $C_{N,t}$ is the consumption of non health goods, $N_{N,t}$ and $N_{H,t}$ are working hours in non-health and health sectors respectively, φ_N and φ_H are the inverses of the Frisch elasticity of labor supply, χ_N and χ_H are the disutilities from working, H_t is the household's health status, σ and η are the inverse of the intertemporal elasticities of substitution for non-health goods consumption and health status, respectively and ψ is the utility weight on health status.

Household seeks to maximize the utility function subject to the following budget constraint:

$$\begin{aligned} & C_{N,t} + I_{N,t} + I_{H,t} + \frac{B_t}{P_{N,t}} + a(u_{H,t})K_{H,t} + a(u_{N,t})K_{N,t} + \\ & \frac{P_{H,t}}{P_{N,t}} w_{N,t} N_{M,t} + \frac{P_{H,t}}{P_{N,t}} C_{H,t} \leq \frac{W_{N,t}}{P_{N,t}} N_{N,t} + \frac{W_{H,t}}{P_{N,t}} N_{H,t} + \\ & \frac{R_{t-1}B_{t-1}}{P_{N,t}} + \frac{K_{N,t}^{eff} R_{N,t}^K}{P_{N,t}} + \frac{K_{H,t}^{eff} R_{H,t}^K}{P_{N,t}} + \frac{Div_t}{P_t} \end{aligned} \tag{2.1.2}$$

where $I_{N,t}$ is the investment of capital in non-health production sector, $I_{H,t}$ is the investment of capital in health production sector , $W_{N,t}$ and $W_{H,t}$ are corresponding nominal wage rates for non-health and health sectors, $P_{N,t}$ and $P_{H,t}$ are price indexes of non-health and health consumption goods, respectively, B_t is an amount of government bonds that pay a nominal gross interest rate of R_t, $\frac{w_{N,t}}{P_{N,t}} N_{M,t}$ is the isolation (hours) represented in terms of consumption goods, $R_{i,t}^k$ is the rental price of effective capital $K_{i,t}^{eff}$, $u_{i,t}$ is the capital utilization rate, $a(u_{i,t})$ is the cost of setting utilization rate $(i = N, H)$ and Div_t are dividends of firms, which are owned by households.

In this model health status of the households is represented as a stock, that is depreciated over time. Therefore households make investment, consisting of medical goods and isolation time, for maintaining their health status. It should be emphasized that the isolation hours are costly for households as they could spent this time by working in the non-health sector. Consequently, the opportunity cost of self isolation is the real wage in the non-health sector.

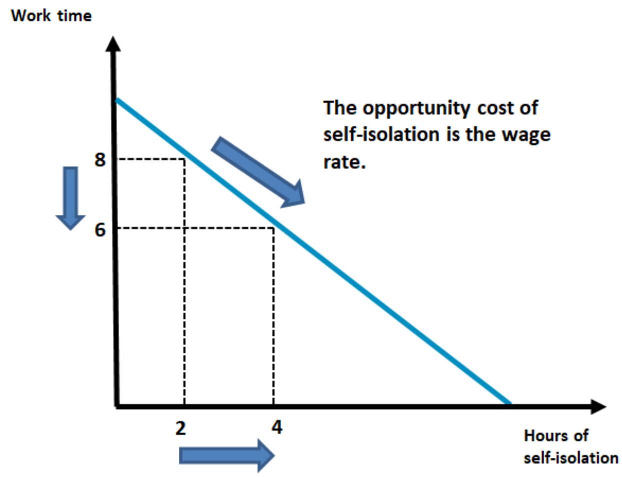


Figure 2: The opportunity cost of the isolation

The occurrence of a health disaster is captured in the following health accumulation equation:

$$H_{t+1} = (1-\delta_h)H_t + C_{H,t}^{\alpha_h}\left(\frac{W_{N,t}}{P_{N,t}}N_{M,t}\right)^{1-\alpha_h} - \varepsilon_t^{covid-19} \tag{2.1.3}$$

where δ_h is the depreciation rate of health, the middle term is health investment conducted by health spending($C_{H,t}$) and isolation $\left(\frac{w_{N,t}}{P_{N,t}}N_{M,t}\right)$. The schematic representation of health stock's accumulation is represented in figure 3.

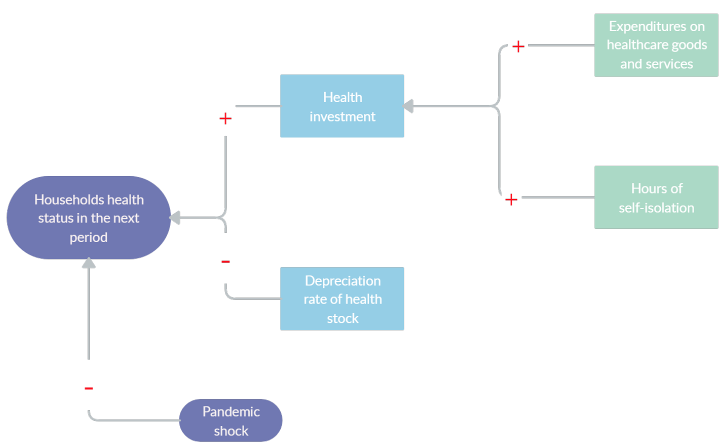


Figure 3: Accumulation of Health Stock

Capital stock evolves according to the following equation:

$$K_{i,t+1} = (1-\delta_i)K_{i,t} + I_{i,t} \quad i = N, H \tag{2.1.4}$$

where δ_i is the depreciation rate of capital. Effective capital is a positive function of capital K_t, utilization u_t and labor N_t:

$$K_{i,t}^{eff} = \gamma_m^i K_{i,t} u_{i,t} N_{i,t}^{\gamma_n^i} \quad i = N, H \tag{2.1.5}$$

(2.1.5) equation shows that if labor supply decreases, it also leads to a decrease in effective capital. Following Christiano et al.(2011), this paper uses the functional form of capital utilization given by:

$$a(u_{i,t}) = \frac{1}{2}\xi_a^i \xi_b^i u_{i,t}^2 + \xi_b^i(1-\xi_a^i)u_{i,t} + \xi_b^i(\frac{\xi_a^i}{2} - 1) \quad i = N, H \tag{2.1.6}$$

where ξ_a and ξ_a are parameters of the function. This function is very convenient for the analysis, because it becomes zero in steady state.

Inserting (2.1.4), (2.1.5) and (2.1.6) into (2.1.2) and maximizing (2.1.1) subject to (2.1.2) and (2.1.1), we get the following first order conditions:

$$C_{N,t}: \quad C_{N,t}^{-\sigma} - \lambda_t = 0 \tag{2.1.7}$$

$$C_{H,t}: \quad -\lambda_t \frac{P_{H,t}}{P_{N,t}} + \mu_t \alpha_h \left(\frac{W_{N,t} N_{M,t}}{P_{N,t} C_{H,t}}\right)^{1-\alpha_h} = 0 \tag{2.1.8}$$

$$N_{N,t}: \quad -\chi_N N_{N,t}^{\varphi_N} + \lambda_t \frac{W_{N,t}}{P_{N,t}} + \lambda_t u_{N,t} \gamma_m \gamma_n N_{N,t}^{\gamma_n - 1} \frac{K_{N,t} R_{N,t}^k}{P_{N,t}} = 0 \tag{2.1.9}$$

$$N_{H,t}: \quad -\chi_H N_{H,t}^{\varphi_H} + \lambda_t \frac{W_{H,t}}{P_{N,t}} + \lambda_t u_{H,t} \gamma_a \gamma_b N_{H,t}^{\gamma_b - 1} \frac{K_{H,t} R_{H,t}^k}{P_{N,t}} = 0 \tag{2.1.10}$$

$$N_{M,t}: \quad -\lambda_t \frac{P_{H,t}}{P_{N,t}} \frac{W_{N,t}}{P_{N,t}} + \mu_t (1-\alpha_h) \left(\frac{W_{N,t}}{P_{N,t}}\right)^{1-\alpha_h} \left(\frac{C_{H,t}}{N_{M,t}}\right)^{\alpha_h} = 0 \tag{2.1.11}$$

$$B_t: \quad -\frac{\lambda_t}{P_{N,t}} + \beta \lambda_{t+1} \frac{R_t}{P_{N,t+1}} = 0 \tag{2.1.12}$$

$$K_{N,t+1}: \quad -\lambda_t + \beta\lambda_{t+1}\Big((u_{N,t+1}\gamma_m N_{N,t+1}^{\gamma_n})\tfrac{R_{N,t+1}^K}{P_{N,t+1}} + (1-\delta_N - a(u_{N,t+1}))\Big) = 0 \tag{2.1.13}$$

$$K_{H,t+1}: \quad -\lambda_t + \beta\lambda_{t+1}\Big((u_{H,t+1}\gamma_a N_{H,t+1}^{\gamma_b})\tfrac{R_{H,t+1}^K}{P_{N,t+1}} + (1-\delta_H - a(u_{H,t+1}))\Big) = 0 \tag{2.1.14}$$

$$H_{t+1}: \quad -\mu_t + \psi H_{t+1}^{-\eta} + \beta\mu_{t+1}(1-\delta_h) = 0 \tag{2.1.15}$$

$$u_{N,t}: \quad \gamma_m N_{N,t}^{\gamma_n} \frac{K_{N,t} R_{N,t}^K}{P_{N,t}} - a(u'_{N,t}) K_{N,t} = 0 \tag{2.1.16}$$

$$u_{H,t}: \quad \gamma_a N_{H,t}^{\gamma_b} \frac{K_{H,t} R_{H,t}^K}{P_{N,t}} - a(u'_{H,t}) K_{H,t} = 0 \tag{2.1.17}$$

where λ_t and μ_t are Lagrange multipliers.

Combining (2.1.7) and (2.1.12) we get the intertemporal consumption equation (Euler equation):

$$C_{N,t}^{\sigma} = \frac{1}{\beta} C_{N,t+1}^{\sigma} \Pi_{N,t+1} R_t^{-1} \tag{2.1.18}$$

Rewriting (2.1.9) and (2.1.10), then using the definition of Lagrangian multiplier, we are left with the household's labor supply equations:

$$\chi_N N_{N,t}^{\varphi_N} C_{N,t}^{\sigma} = \frac{W_{N,t}}{P_{N,t}} + u_{N,t} \gamma_m \gamma_n N_{N,t}^{\gamma_n - 1} \frac{K_{N,t} R_{N,t}^k}{P_{N,t}} \tag{2.1.19}$$

$$\chi_H N_{H,t}^{\varphi_H} C_{N,t}^{\sigma} = \frac{W_{H,t}}{P_{N,t}} + u_{H,t} \gamma_a \gamma_b N_{H,t}^{\gamma_b - 1} \frac{K_{H,t} R_{H,t}^k}{P_{N,t}} \tag{2.1.20}$$

Substituting λ_t by $C_{N,t}^{-\sigma}$ in equations (1.1.13) and (1.1.14), capital supply equations get the form:

$$\beta \left(\frac{C_{N,t}}{C_{N,t+1}} \right)^{\sigma} \left((u_{N,t+1} \gamma_m N_{N,t+1}^{\gamma_n}) \frac{R_{N,t+1}^K}{P_{N,t+1}} + (1 - \delta_N - a(u_{N,t+1})) \right) = 1 \tag{2.1.21}$$

$$\beta \left(\frac{C_{N,t}}{C_{N,t+1}} \right)^{\sigma} \left((u_{H,t+1} \gamma_a N_{H,t+1}^{\gamma_b}) \frac{R_{H,t+1}^K}{P_{N,t+1}} + (1 - \delta_H - a(u_{H,t+1})) \right) = 1 \tag{2.1.22}$$

Combining (2.1.8) and (2.1.11) we get that consumption of health goods is proportional to isolation hours:

$$\frac{W_{N,t}}{P_{N,t}} N_{M,t} = \frac{1 - \alpha_h}{\alpha_h} C_{H,t} \tag{2.1.23}$$

From (2.1.15):

$$\beta \left(\psi H_{t+1}^{-\eta} + \left(\frac{C_{H,t+1}}{w_{N,t+1} N_{M,t+1}} \right)^{1-\alpha_h} \frac{1}{\alpha_h} \frac{P_{H,t+1}}{P_{N,t+1}} \frac{1-\delta_h}{C_{N,t+1}^{\sigma}} \right) = \left(\frac{C_{H,t}}{w_{N,t} N_{M,t}} \right)^{1-\alpha_h} \frac{1}{\alpha_h} \frac{P_{H,t}}{P_{N,t}} \frac{1}{C_{N,t}^{\sigma}} \tag{2.1.24}$$

which determines the optimality condition for health investment.

Rewriting (2.1.16) and (2.1.17) we are left with optimality conditions for capital utilization rate:

$$\xi_m \xi_n u_{N,t} + \xi_n (1 - \xi_m) = \gamma_m N_{N,t}^{\gamma_n} \frac{R_{N,t}^K}{P_{N,t}} \tag{2.1.25}$$

$$\xi_a \xi_b u_{H,t} + \xi_b (1 - \xi_a) = \gamma_a N_{H,t}^{\gamma_b} \frac{R_{H,t}^K}{P_{N,t}} \tag{2.1.26}$$

2.2 Firms

On the production side, there are two sectors: health sector and non-health sector.

2.2.1 Health goods production

Final health good producers modify all intermediate inputs into total output in health care sector and minimize their total expenditures. As a result, we get demand function for health goods:

$$Y_{H,t}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\varepsilon_H} Y_{H,t} \tag{2.2.1}$$

The intermediate health goods producers operate in monopolistically competitive market and use Cobb-Douglas production function for health goods production:

$$Y_{H,t} = A_{H,t}(K_{H,t}^{eff})^{\alpha_H}(N_{H,t}H_t)^{1-\alpha_H} \tag{2.2.2}$$

where $A_{H,t}$ is the cyclical technological process and α_H is the share of effective capital in production function.

The intermediate health goods producers seek to maximize their profits, which results in an optimal allocation of effective capital and labor:

$$\frac{r_{H,t}^k}{w_{H,t}^r} = \frac{\alpha_H}{1-\alpha_H}\frac{N_{H,t}}{K_{H,t}^{eff}} \tag{2.2.3}$$

Real marginal cost of health sector is a function of real wage and real rent of effective capital along with health stock and temporary productivity

$$MC_{H,t} = \left(\frac{r_{H,t}^k}{\alpha_H}\right)^{\alpha_H}\left(\frac{w_{H,t}^r}{1-\alpha_H}\right)^{1-\alpha_H}\frac{1}{A_{H,t}H_t^{1-\alpha_H}}\frac{P_{N,t}}{P_{H,t}} \tag{2.2.4}$$

Firms set prices following à la Calvo (1983): only the $(1-\theta)$ fraction of intermediate firms can reoptimize its prices. Solving price setting problem we derive nonlinear Phillips curve as in Sims et al. (2019):

$$x_{1,t}^H = \frac{Y_{H,t}MC_{H,t}}{C_{N,t}^\sigma} + \theta_H\beta\Pi_{H,t+1}^{\varepsilon_H}x_{1,t+1}^H \tag{2.2.5}$$

$$x_{2,t}^H = \frac{Y_{H,t}}{C_{N,t}^\sigma} + \theta_H\beta\Pi_{H,t+1}^{\varepsilon_H-1}x_{2,t+1}^H \tag{2.2.6}$$

$$\Pi_{H,t}^* = \frac{\varepsilon_H}{\varepsilon_H-1}\Pi_{H,t}\frac{x_{1,t}^H}{x_{2,t}^H} \tag{2.2.7}$$

$$\Pi_{H,t}^{1-\varepsilon_H} = \theta_H + (1-\theta_H)(\Pi_{H,t}^*)^{1-\varepsilon_H} \tag{2.2.8}$$

2.2.2 Non health goods production

The problems for intermediaries and final good producers in non health sector identical to the health care sector.
The production function of intermediate non health goods is represented by the following Cobb-Douglas function:

$$Y_{N,t} = A_{N,t}(K^{eff}_{N,t})^{\alpha_N}(N_{N,t}H_t)^{1-\alpha_N} \tag{2.2.9}$$

The equations for optimal allocation of resources and real marginal cost are as follows:

$$\frac{r^k_{N,t}}{w^r_{N,t}} = \frac{\alpha_N}{1-\alpha_N}\frac{N_{N,t}}{K^{eff}_{N,t}} \tag{2.2.10}$$

$$MC_{N,t} = \left(\frac{r^k_{N,t}}{\alpha_N}\right)^{\alpha_N}\left(\frac{w^r_{N,t}}{1-\alpha_N}\right)^{1-\alpha_N}\frac{1}{A_{N,t}H_t^{1-\alpha_N}} \tag{2.2.11}$$

Phillips curve of non health sector goods is given by the set of following equations.

$$x^N_{1,t} = \frac{Y_{N,t}MC_{N,t}}{C^{\sigma}_{N,t}} + \theta_N\beta\Pi^{\varepsilon_N}_{N,t+1}x^N_{1,t+1} \tag{2.2.12}$$

$$x^N_{2,t} = \frac{Y_{N,t}}{C^{\sigma}_{N,t}} + \theta_N\beta\Pi^{\varepsilon_N-1}_{N,t+1}x^N_{2,t+1} \tag{2.2.13}$$

$$\Pi^*_{N,t} = \frac{\varepsilon_N}{\varepsilon_N-1}\Pi_{N,t}\frac{x^N_{1,t}}{x^N_{2,t}} \tag{2.2.14}$$

$$\Pi^{1-\varepsilon_N}_{N,t} = \theta_N + (1-\theta_N)(\Pi^*_{N,t})^{1-\varepsilon_N} \tag{2.2.15}$$

2.3 Market Clearing Conditions

On the one hand, output of the health sector is divided into health goods consumption and isolation:

$$Y_{H,t} = C_{H,t} + \frac{W_{N,t}}{P_{N,t}}N_{M,t} \tag{2.3.1}$$

On the other hand, the production of the non health goods is the sum of the non health consumption, investment in the health and non health sectors and the capital utilization costs of both sectors.

$$Y_{N,t} = C_{N,t} + I_{N,t} + I_{H,t} + a(u_{N,t})K_{N,t} + a(u_{H,t})K_{H,t} \tag{2.3.2}$$

2.4 Monetary Policy

To complete the model, the endogenous interest rate must be set by the monetary authority. We assume that the monetary authority implements inflation targeting policy via Taylor-type interest rate rule:

$$R_t = \left(\frac{R_{t-1}}{R^{ss}}\right)^{\rho_r} \left\{ \left(\frac{\Pi_{N,t+1}}{\Pi_N^{ss}}\right)^{\mu_\pi} \left(\frac{Y_{N,t}+Y_{H,t}}{Y_N^{ss}+Y_H^{ss}}\right)^{\mu_y} \right\}^{(1-\rho_r)} \quad (2.4.1)$$

The Central bank's rule has some persistence and reacts to non-health goods inflation expectations and the output deviation from its steady state.

3 Calibration

This section presents our baseline calibration. The model is calibrated on a quarterly basis. First, we discuss the parameters, which differ within sectors. Particularly, we set the price stickiness parameter of non-health goods to 0.8, i.e. prices stay unchanged for five quarters on average. By contrast, we calibrate the price stickiness parameter of health goods $\theta_H = 0.5$ (prices stay unchanged for 2 quarters on average), here we make assumption that during health shock the price of health related goods is more flexible compared to normal times, when the price stickiness of health and non-health goods would be very close to each other or even the vice versa.

The labor supply elasticity parameter of non-health sector, φ_N, is set to 1.2 and the same parameter for health production sector is set to 2.5 indicating that all other things being equal, people are more willing to work in non-health sector due to the risk of getting infected (the common value of this parameter is 2 (see Christiano et al. (2009)). As for disutility parameters from working, we set $\chi_N = 2$ and $\chi_H = 8$ (non-health and health sector respectively) indicating the fact that in equilibrium the steady state level of employment in non-health sector is higher.

For the rest of parameters that are presented in two sectors we set equal to each other for not imposing further heterogeneity among this sectors, namely α, share of capital in production function, is set to 0.5 for both sectors and we choose δ_H and δ_N (depreciation rates of capital stocks) to be 0.03.

Now we turn to the parameters directly related to health stock, namely, depreciation rate of health stock (δ_h), share of health goods in health investment (α_h), the utility weight on health status (ψ) and the intertemporal elasticity of substitution for health status (η). They are set 0.025, 0.25, 1.1 and 3 respectively. These parameters are not common, because the health sector is not modeled explicitly in DSGE framework at least prior to COVID-19 pandemic. Thus, this parameters are calibrated based on our knowledge of their nature (for example, we assume that, on average, people consume less medical goods for maintaining their health level compared to leading a healthy lifestyle), and to match the data reported worldwide regarding the effects of pandemic. As an extension, we also do model sensitivity analysis with respect to this parameters to see to what extent they affect the impulse response functions of health shock.

For the rest of the parameters presented in the model we set following values. The coefficient of the inverse of the intertemporal elasticity of substitution for non-health goods consumption (σ) is 1.1, the discount factor β is 0.99, implying annual real interest rate of 4%. We set ε_H and ε_N (the elasticity of substitution among intermediate goods for health and non-health sector) to be 5 and 6 respectively, implying 25% and 20% mark-up in steady state.

The coefficients of the reaction of interest rate to inflation expectations μ_π and output gap μ_y are set 1.2 and 0.2 respectively. The value of the smoothing parameter in Taylor type rule ρ_r is calibrated to 0.6. This calibration is very close to values used in the literature.

4 Results

This section discuses the dynamics of the main variables of the model in response to health shock and discusses the response of monetary policy to health shock, and does some sensitivity analysis as well.

4.1 Impulse responses to health shock

Figure 4 displays the impulse response functions to a negative health shock, which indicates the extent of outbreak of covid-19 pandemic in the economy. Health shock is calibrated in a way to have a quarter on quarter decline in GDP growth of 10%.

Negative health shock decreases health status of the households by generating negative health stock. The accumulation of health shows a positive correlation between isolation and health shock. Therefore the more hard hits the shock, people become more isolated in order to recover their health. As a result, health stock converges its steady state about 50 periods later.

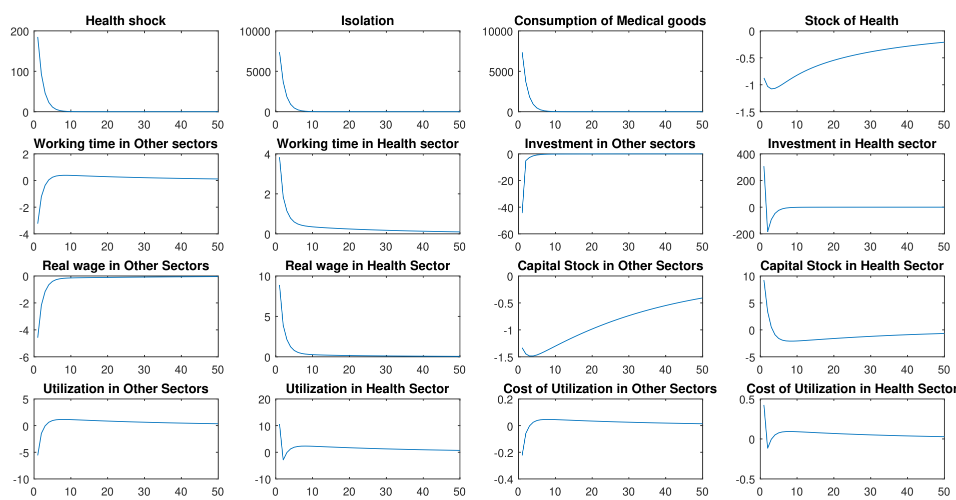
During pandemic, households increase their demand for medical goods and decrease the consumption of non-health goods. To meet the additional demand, firms in health sector hire more labor. On the other hand, output in other sectors decreases. Wages respond similarly. Real wage increases in health sector due to higher labor demand and decreases in other sectors. As a result, labor increases in health sector and decreases in non-health sector.

As shown in equations (2.2.4) and (2.2.11), marginal costs are an increasing function of real wages and a decreasing function of health stock. Particularly, in health goods sector higher wages bring marginal costs up, which creates inflation. The decrease in real wages in non health goods sector shrinks marginal costs. Yet, the effect of the decrease in health stock exceeds and marginal costs still go up. The reason of higher growth in non health sector marginal costs is that in health goods sector marginal cost also depends on the relative price of health to non health goods negatively. The relative price of health to non health goods increases and health goods become relatively expensive. This fact restricts the increase of marginal cost in health goods sector.

In health sector prices are more flexible and the price elasticity of marginal cost is higher. This creates higher inflation. On the other hand, the presence of price stickiness in non health goods sector prevents inflation and emerges a deflation. Monetary authority conducts expansionary monetary policy by dropping interest rates.

Higher demand in health goods sector also requires more investments to boost production. This leads to an increase of investments in health sector and decline in other sectors. As a result, more capital is accumulated and utilized as a component of effective capital. The use of capital shifts from other sectors to health sector. That's why both capital and utilization of capital increase in health sector and decline in other sectors. Therefore by increasing the capital utilization the latter's cost also increases in health sector and decreases in other sectors accordingly. As a growing function of capital stock and utilization of capital, effective capital also increases in health sector and declines in other sectors.

Effective capital and labor are considered as inputs in the production. Thus increase of production factors in health sector entails an increase of production itself. The output in other sectors declines. Because in the overall production the share of other sectors is greater than that of health sector, total output declines. As a percent change in gross domestic product (GDP), economic growth declines by about 10%.



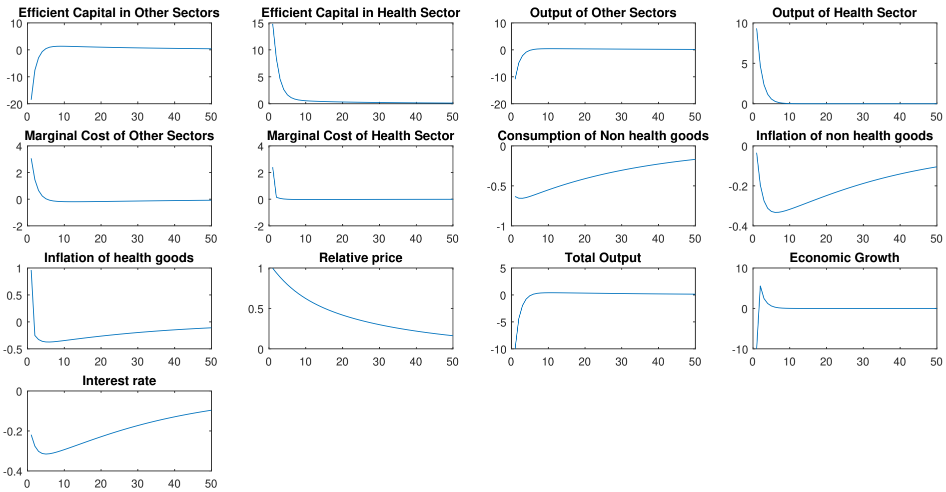


Figure 4: Impulse responses to health shock

4.2 Sensitivity analysis

In this section we provide a sensitivity analysis to assess the results of health shock by changing the values of some structural parameters of the model. First, we check to what extent the impulse response functions of health shock depend on some health related parameters. Figure 6 (Appendix D) shows the IRFs of health shock for 2 alternative calibrations of depreciation rate of health stock together with baseline calibration. First, we set $\delta_h = 0.01$ so health status (stock) depreciates in slower pace and then we set it to be 0.15 to see the adverse situation. For the second case (figure 7) we change the parameter of health share in utility function. Applying the same logic as for the depreciation rate we first set it equal to 0.4 and then 8. For η (the intertemporal elasticity of substitution for health status) we set $\eta = 2$ and $\eta = 8$ (figure 8). The results show that though the size of responses for some variables changes, but the sign and dynamics of this responses remain almost the same (we do not see any change in the sign).

We also do sensitivity analysis for policy function parameter μ_π (figure 9), which shows to what extent Central bank reacts to expected inflation changes from its steady state value. We set $\mu_\pi = 50$ (this value is very big). Comparing this results with the baseline scenario we can see that although at the first period the stock of health drops less compared to baseline calibration it decreases more rapidly and reaches its minimum point which is bigger in absolute value compared to baseline scenario. However, it reaches to its minimum point later. So, we can conclude that implying stronger policy delays the stock of health from achieving its minimum value.

4.3 Impulse responses to simultaneous health and monetary policy shocks

Now we turn to health and monetary policy shocks conducted simultaneously, which is captured in figure 5. By mentioning monetary policy shock one can refer to negative shock to nominal interest rate. The following unanticipated temporary decrease in the nominal interest rate (deviation from Taylor rule) raises demand for non health goods. This forces firms to increase labor demand in other sectors and pushes up real wages. Higher wages motivate households to supply more working time in other sectors. As a result, expansionary monetary policy mitigates the reduction of total output and economic growth. Although output declines less in the presence of expansionary monetary policy shock, it worsens the health condition of households by lowering the stock of health. On the contrary, more restricted economic activity mitigates the spread of infection and flattens declining curve of health stock. Hence, there is a trade-off between the recession severity and the health status of the epidemic.[1]

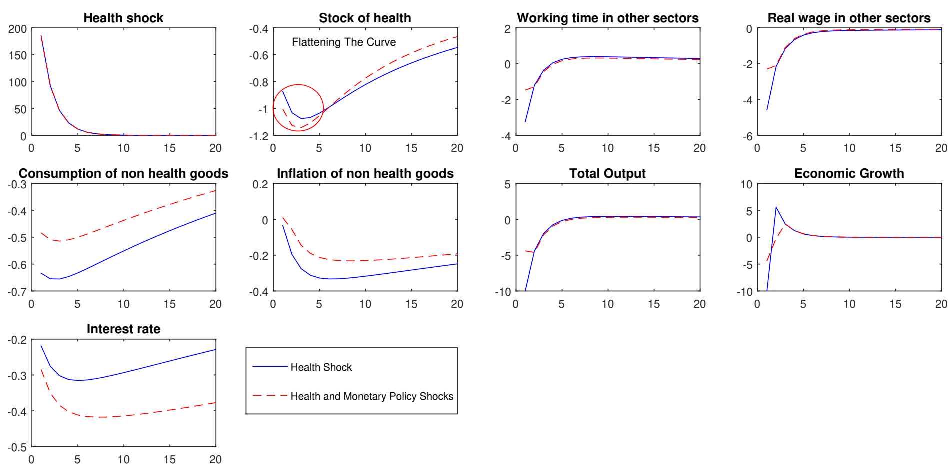


Figure 5: Impulse responses to simultaneous health and monetary policy shocks

[1] Eichenbaum M. S., Rebelo S., Trabandt M. make a similar statement in "The macroeconomics of epidemics" research paper.

5 Conclusion

In this paper we incorporate health block into standard New Keynesian closed economy DSGE model. To do this we split the production into health and non health sectors and investigate the behaviour of households, firms and monetary authority in the model. Health status is modeled as a stock with depreciation rate and investment. Households invest in their health by consuming medical goods and isolating from society. We study the impact on the main macroeconomic variables of negative health shock, which embodies the outbreak of COVID-19 pandemic in the economy. We obtain that many macroeconomic variables, such as consumption, investment, real wages, labor supply, capital and its utilization, cost of utilization, output and inflation, are decreasing in non health sector and switch to health sector. The key result of the analysis is the decreases of health stock, inflation and total output, which leads to the decline in interest rate.

We also analyze the consequences of expansionary macroeconomic policy conducted by monetary authorities. Although the reduction of interest rate mitigates the loss of total output, it deepens the decline of health stock curve. Thus in order to flatten the curve and to improve society's health condition, the authorities have to restrict the economic activity by allowing a recession with higher severity in the economy. In other words, there exists a trade-off between economic and health consequences caused by epidemic. Results are in line with results obtained by Eichenbaum et al. (2020).

There are some potential issues regarding further research worth to be noted. First it would be better to extent the model by constructing a small open economy DSGE model and including risk premium with health shock, which would introduce additional uncertainty.

Furthermore, one can add capital transformation from one production sector to another. It does not give so much benefit from monetary policy perspective, though. The problem is partially solved by introducing effective capital into model, which is presented as a function of capital stock and utilization of capital.

We can also introduce government into model with its tools to perceive the optimal policy response to stabilize health crisis.

Finally, we can insert a health shock along with a liquidity shock to get closer to reality.

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6 Appendix

6.1 Appendix A. The Steady State

In this subsection, we compute the steady state of the model. First, we assume that in steady state the capital utilization costs are equal to zero:

$$a(u_H) = 0 \tag{6.1.1}$$

$$a(u_N) = 0 \tag{6.1.2}$$

and the follwoing variables are equal to one:

$$A_H = 1 \tag{6.1.3}$$

$$A_N = 1 \tag{6.1.4}$$

$$u_H = 1 \tag{6.1.5}$$

$$u_N = 1 \tag{6.1.6}$$

$$H = 1 \tag{6.1.7}$$

$$\frac{P_H}{P_N} = 1 \tag{6.1.8}$$

$$\Pi_H = \Pi_N = \Pi_H^* = \Pi_N^* = 1 \tag{6.1.9}$$

For solving the steady state model we endogenize fixed costs and some parameters:

$$\Phi_N = Y_{N,t} - C_{N,t} - I_{N,t} - I_{H,t} \tag{6.1.10}$$

$$\Phi_H = Y_{H,t} - C_{H,t} - \frac{W_{N,t}}{P_{N,t}} N_{M,t} \tag{6.1.11}$$

$$\gamma_m = \frac{1}{N_N^{\gamma_n}} \tag{6.1.12}$$

$$\gamma_a = \frac{1}{N_H^{\gamma_b}} \tag{6.1.13}$$

$$\xi_b = r_N^K \tag{6.1.14}$$

$$\xi_n = r_H^K \tag{6.1.15}$$

Steady state value of marginal cost is the vice versa of markup:

$$MC_H = \frac{\varepsilon_H - 1}{\varepsilon_H} \tag{6.1.16}$$

$$MC_N = \frac{\varepsilon_N - 1}{\varepsilon_N} \tag{6.1.17}$$

Solving the equation (2.1.18) in a steady state we get:

$$R = \frac{1}{\beta} \tag{6.1.18}$$

Using (2.1.21) and (2.1.22) , steady states of $r^k_{H,t}$ and $r^k_{N,t}$ can be represented by the following:

$$r^K_N = \frac{1}{\beta} - (1-\delta_N) \tag{6.1.19}$$

$$r^K_H = \frac{1}{\beta} - (1-\delta_H) \tag{6.1.20}$$

From (2.2.4) and (2.2.11):

$$w_N = MC_N(\alpha_N)^{\alpha_N}(1-\alpha_N)^{1-\alpha_N}\left(\frac{1}{r^K_N}\right)^{\alpha_N} \tag{6.1.21}$$

$$w_H = MC_H(\alpha_H)^{\alpha_H}(1-\alpha_H)^{1-\alpha_H}\left(\frac{1}{r^K_H}\right)^{\alpha_H} \tag{6.1.22}$$

Combining (2.1.23) and (2.1.24) in steady state we find the value of non-health consumption:

$$C_N = \left[\left(\frac{1}{\beta\alpha_h}\left(\frac{\alpha_h}{1-\alpha}\right)^{1-\alpha_h} - \left(\frac{\alpha_h}{1-\alpha}\right)^{1-\alpha_h}\frac{(1-\delta_h)}{\alpha_h}\right)\frac{1}{\psi}\right]^{\frac{1}{\sigma}} \tag{6.1.23}$$

Steady state values of $N_{N,t}$ and $N_{H,t}$ can be found from labor supply equations:

$$N_N = \left[(w_N + \gamma_n\frac{\alpha_N}{1-\alpha_N}w_N)\frac{1}{\chi_N}\frac{1}{C^\sigma_N}\right]^{\frac{1}{\varphi_N}} \tag{6.1.24}$$

$$N_H = \left[(w_H + \gamma_b\frac{\alpha_H}{1-\alpha_H}w_H)\frac{1}{\chi_H}\frac{1}{C^\sigma_N}\right]^{\frac{1}{\varphi_H}} \tag{6.1.25}$$

Writing (2.2.3) and (2.2.10) in steady state we get:

$$K_N = \frac{\alpha_N}{1-\alpha_N}\frac{w_N}{r^K_N}N_N \tag{6.1.26}$$

$$K_H = \frac{\alpha_H}{1-\alpha_H}\frac{w_H}{r^K_H}N_H \tag{6.1.27}$$

Combining (2.1.3) and (2.1.23) we are left with the steady state value of health goods consumption:

$$C_H = \delta_h\left(\frac{\alpha_h}{1-\alpha_h}\right)^{1-\alpha_h} \tag{6.1.28}$$

The steady state values for the rest of variables are following.

$$N_M = \frac{1-\alpha_h}{\alpha_h}C_H\frac{1}{w_N} \tag{6.1.29}$$

$$K_N^{ff} = K_N \tag{6.1.30}$$

$$K_H^{ff} = K_H \tag{6.1.31}$$

$$Y_H = N_H^{1-\alpha_H} K_H^{\alpha_H} \tag{6.1.32}$$

$$Y_N = N_N^{1-\alpha_N} K_N^{\alpha_N} \tag{6.1.33}$$

$$I_H = \delta_H K_H \tag{6.1.34}$$

$$I_N = \delta_N K_N \tag{6.1.35}$$

$$x_1^H = \frac{1}{C_N^\sigma} \frac{Y_H MC_H}{1 - \theta\beta(\Pi_H)_H^\varepsilon} \tag{6.1.36}$$

$$x_2^H = \frac{1}{C_N^\sigma} \frac{Y_H}{1 - \theta\beta(\Pi_H)^{\varepsilon_H - 1}} \tag{6.1.37}$$

$$x_1^N = \frac{1}{C_N^\sigma} \frac{Y_N MC_N}{1 - \theta\beta(\Pi_N)_N^\varepsilon} \tag{6.1.38}$$

$$x_2^N = \frac{1}{C_N^\sigma} \frac{Y_N}{1 - \theta\beta(\Pi_N)^{\varepsilon_N - 1}} \tag{6.1.39}$$

6.2 Appendix B. Model equations

1. Euler equation

$$C_{N,t}^{\sigma} = \frac{1}{\beta} C_{N,t+1}^{\sigma} \Pi_{N,t+1} R_t^{-1} \tag{6.2.1}$$

2. Labor supply in non-health sector

$$\chi_N N_{N,t}^{\varphi_N} C_{N,t}^{\sigma} = \frac{W_{N,t}}{P_{N,t}} + u_{N,t} \gamma_m \gamma_n N_{N,t}^{\gamma_n - 1} \frac{K_{N,t} R_{N,t}^{k}}{P_{N,t}} \tag{6.2.2}$$

3. Labor supply in health sector

$$\chi_H N_{H,t}^{\varphi_H} C_{N,t}^{\sigma} = \frac{W_{H,t}}{P_{N,t}} + u_{H,t} \gamma_a \gamma_b N_{H,t}^{\gamma_b - 1} \frac{K_{H,t} R_{H,t}^{k}}{P_{N,t}} \tag{6.2.3}$$

4. Capital supply in non-health sector

$$\beta \left(\frac{C_{N,t}}{C_{N,t+1}} \right)^{\sigma} \left((u_{N,t+1} \gamma_m N_{N,t+1}^{\gamma_n}) \frac{R_{N,t+1}^{K}}{P_{N,t+1}} + (1 - \delta_N - a(u_{N,t+1})) \right) = 1 \tag{6.2.4}$$

5. Capital supply in health sector

$$\beta \left(\frac{C_{N,t}}{C_{N,t+1}} \right)^{\sigma} \left((u_{H,t+1} \gamma_a N_{H,t+1}^{\gamma_b}) \frac{R_{H,t+1}^{K}}{P_{N,t+1}} + (1 - \delta_H - a(u_{H,t+1})) \right) = 1 \tag{6.2.5}$$

6. Health care time decision

$$\frac{W_{N,t}}{P_{N,t}} N_{M,t} = \frac{1 - \alpha_h}{\alpha_h} C_{H,t} \tag{6.2.6}$$

7. Health investment decision

$$\beta \left(\psi H_{t+1}^{-\eta} + \left(\frac{C_{H,t+1}}{w_{N,t+1} N_{M,t+1}} \right)^{1-\alpha_h} \frac{1}{\alpha_h} \frac{P_{H,t+1}}{P_{N,t+1}} \frac{1-\delta_h}{C_{N,t+1}^{\sigma}} \right) = \left(\frac{C_{H,t}}{w_{N,t} N_{M,t}} \right)^{1-\alpha_h} \frac{1}{\alpha_h} \frac{P_{H,t}}{P_{N,t}} \frac{1}{C_{N,t}^{\sigma}} \tag{6.2.7}$$

8. Non-health capital utilization decision

$$\xi_m \xi_n u_{N,t} + \xi_n (1 - \xi_m) = \gamma_m N_{N,t}^{\gamma_n} \frac{R_{N,t}^{K}}{P_{N,t}} \tag{6.2.8}$$

9. Health capital utilization decision

$$\xi_a \xi_b u_{H,t} + \xi_b (1 - \xi_a) = \gamma_a N_{H,t}^{\gamma_b} \frac{R_{H,t}^{K}}{P_{N,t}} \tag{6.2.9}$$

10. Health accumulation

$$H_{t+1} = (1 - \delta_h) H_t + C_{H,t}^{\alpha_h} \left(\frac{W_{N,t}}{P_{N,t}} N_{M,t} \right)^{1-\alpha_h} - \varepsilon_t^{covid-19} \tag{6.2.10}$$

11. Health capital's law of motion

$$K_{H,t+1} = (1 - \delta_H)K_{H,t} + I_{H,t} \tag{6.2.11}$$

12. Non-health capital's law of motion

$$K_{N,t+1} = (1 - \delta_N)K_{N,t} + I_{N,t} \tag{6.2.12}$$

13. Effective non-health capital

$$K^{eff}_{N,t} = \gamma_m K_{N,t} u_{N,t} N^{\gamma_n}_{N,t} \tag{6.2.13}$$

14. Effective health capital

$$K^{eff}_{H,t} = \gamma_a K_{H,t} u_{H,t} N^{\gamma_b}_{H,t} \tag{6.2.14}$$

15. Health capital utilization cost

$$a(u_{H,t}) = \frac{1}{2}\xi_a \xi_b u^2_{H,t} + \xi_b(1 - \xi_a)u_{H,t} + \xi_b(\frac{\xi_a}{2} - 1) \tag{6.2.15}$$

16. Non-health capital utilization cost

$$a(u_{N,t}) = \frac{1}{2}\xi_m \xi_n u^2_{N,t} + \xi_n(1 - \xi_m)u_{N,t} + \xi_n(\frac{\xi_m}{2} - 1) \tag{6.2.16}$$

17. Relative price

$$\frac{S_t}{S_{t-1}} = \frac{\Pi_{H,t}}{\Pi_{N,t}} \tag{6.2.17}$$

18. Health firms' production function

$$Y_{H,t} = A_{H,t}(K^{eff}_{H,t})^{\alpha_H}(N_{H,t}H_t)^{1-\alpha_H} \tag{6.2.18}$$

19. Non-health firms' production function

$$Y_{N,t} = A_{N,t}(K^{eff}_{N,t})^{\alpha_N}(N_{N,t}H_t)^{1-\alpha_N} \tag{6.2.19}$$

20. Optimal allocation of resources in health sector

$$\frac{r^k_{H,t}}{w^r_{H,t}} = \frac{\alpha_H}{1 - \alpha_H}\frac{N_{H,t}}{K^{eff}_{H,t}} \tag{6.2.20}$$

21. Optimal allocation of resources in non-health sector

$$\frac{r^k_{N,t}}{w^r_{N,t}} = \frac{\alpha_N}{1 - \alpha_N}\frac{N_{N,t}}{K^{eff}_{N,t}} \tag{6.2.21}$$

22. Real marginal cost of health firms

$$MC_{H,t} = \left(\frac{r^k_{H,t}}{\alpha_H}\right)^{\alpha_H}\left(\frac{w^r_{H,t}}{1 - \alpha_H}\right)^{1-\alpha_H}\frac{1}{A_{H,t}H^{1-\alpha_H}_t}\frac{1}{S_t} \tag{6.2.22}$$

23. Real marginal cost of non-health firms

$$MC_{N,t} = \left(\frac{r^k_{N,t}}{\alpha_N}\right)^{\alpha_N}\left(\frac{w^r_{N,t}}{1-\alpha_N}\right)^{1-\alpha_N}\frac{1}{A_{N,t}H_t^{1-\alpha_N}} \tag{6.2.23}$$

24. First auxiliary variable of health goods Phillips curve

$$x^H_{1,t} = \frac{Y_{H,t}MC_{H,t}}{C^{\sigma}_{N,t}} + \theta_H\beta\Pi^{\varepsilon_H}_{H,t+1}x^H_{1,t+1} \tag{6.2.24}$$

25. Second auxiliary variable of health goods Phillips curve

$$x^H_{2,t} = \frac{Y_{H,t}}{C^{\sigma}_{N,t}} + \theta_H\beta\Pi^{\varepsilon_H-1}_{H,t+1}x^H_{2,t+1} \tag{6.2.25}$$

26. Optimal inflation of health goods

$$\Pi^*_{H,t} = \frac{\varepsilon_H}{\varepsilon_H-1}\Pi_{H,t}\frac{x^H_{1,t}}{x^H_{2,t}} \tag{6.2.26}$$

27. The aggregate inflation dynamics of health goods

$$\Pi^{1-\varepsilon_H}_{H,t} = \theta_H + (1-\theta_H)(\Pi^*_{H,t})^{1-\varepsilon_H} \tag{6.2.27}$$

28. First auxiliary variable of non-health goods Phillips curve

$$x^N_{1,t} = \frac{Y_{N,t}MC_{N,t}}{C^{\sigma}_{N,t}} + \theta_N\beta\Pi^{\varepsilon_N}_{N,t+1}x^N_{1,t+1} \tag{6.2.28}$$

29. Second auxiliary variable of non-health goods Phillips curve

$$x^N_{2,t} = \frac{Y_{N,t}}{C^{\sigma}_{N,t}} + \theta_N\beta\Pi^{\varepsilon_N-1}_{N,t+1}x^N_{2,t+1} \tag{6.2.29}$$

30. Optimal inflation of non-health goods

$$\Pi^*_{N,t} = \frac{\varepsilon_N}{\varepsilon_N-1}\Pi_{N,t}\frac{x^N_{1,t}}{x^N_{2,t}} \tag{6.2.30}$$

31. The aggregate inflation dynamics of non-health goods

$$\Pi^{1-\varepsilon_N}_{N,t} = \theta_N + (1-\theta_N)(\Pi^*_{N,t})^{1-\varepsilon_N} \tag{6.2.31}$$

32. Market clearing condition of health sector

$$Y_{H,t} = C_{H,t} + \frac{W_{N,t}}{P_{N,t}}N_{M,t} - \Phi_H \tag{6.2.32}$$

33. Market clearing condition of non-health sector

$$Y_{N,t} = C_{N,t} + I_{N,t} + I_{H,t} + a(u_{N,t})K_{N,t} + a(u_{H,t})K_{H,t} - \Phi_N \tag{6.2.33}$$

34. Taylor rule

$$R_t = \left(\frac{R_{t-1}}{R^{ss}}\right)^{\rho_r} \left\{ \left(\frac{\Pi_{N,t+1}}{\Pi_N^{ss}}\right)^{\mu_\pi} \left(\frac{Y_{N,t} + Y_{H,t}}{Y_N^{ss} + Y_H^{ss}}\right)^{\mu_y} \right\}^{(1-\rho_r)} \tag{6.2.34}$$

35. Productivity of non-health goods

$$A_{N,t} = \rho_{a_N} A_{N,t-1} + (1 - \rho_{a_N}) A_N^{ss} + \sigma_{a_N,t} \tag{6.2.35}$$

36. Productivity of health goods

$$A_{H,t} = \rho_{a_H} A_{H,t-1} + (1 - \rho_{a_H}) A_H^{ss} + \sigma_{a_H,t} \tag{6.2.36}$$

37.Health shock

$$\varepsilon_t^{covid-19} = \rho_h \varepsilon_{t-1}^{covid-19} + \sigma_{h,t} \tag{6.2.37}$$

6.3 Appendix C. Calibration

Parameter	Description	Value
β	Discount factor	0.99
θ_N	Price stickiness of non-health goods	0.8
θ_H	Price stickiness of health goods	0.5
α_N	Share of capital in non-health production sector	0.5
α_H	Share of capital in health production sector	0.5
α_h	Share of health goods in health investment	0.25
δ_N	Depreciation rate of capital in non-health production sector	0.03
δ_H	Depreciation rate of capital in health production sector	0.03
δ_h	Depreciation rate of health	0.025
φ_N	Labor supply elasticity in non-health sector	1.2
φ_H	Labor supply elasticity in health sector	2.5
ρ	Interest rate persistence	0.6
ϕ_π	Reaction to inflation expectations	1.2
ϕ_y	Reaction to output	0.2
ξ_N	Disutility coefficient of labor supply in non-health sector	2
ξ_H	Disutility coefficient of labor supply in health sector	8
ϕ	Utility weight on health status	1.1
η	Intertemporal elasticity of substitution for health status	3
σ	Inverse of the intertemporal elasticity of substitution for non-health goods consumption	1.1
ε_N	The elasticity of substitution between varieties of intermediate non-health goods	6
ε_H	The elasticity of substitution between varieties of intermediate health goods	5
ξ_a	Parameter in capital utilization of health capital	0.2
ξ_m	Parameter in capital utilization of non-health capital	0.4

Table 1: Calibration

6.4 Appendix D. Sensitivity Analysis

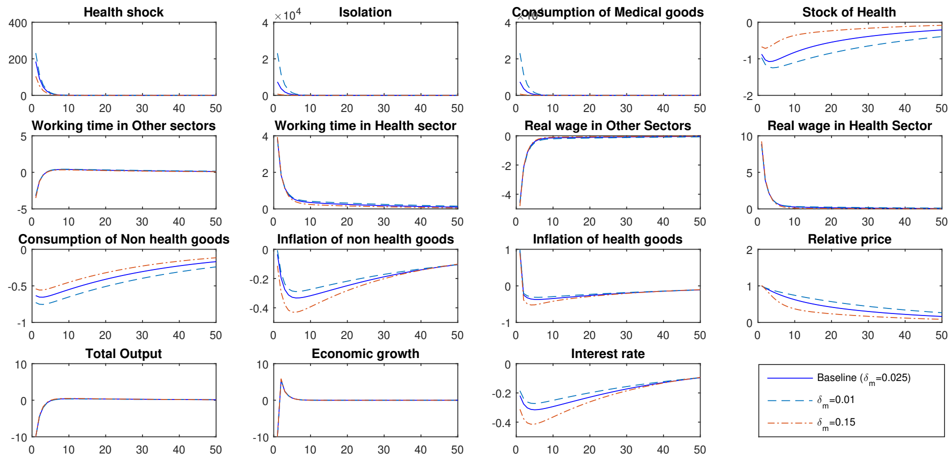

Figure 6: Health shock (sensitivity analysis)

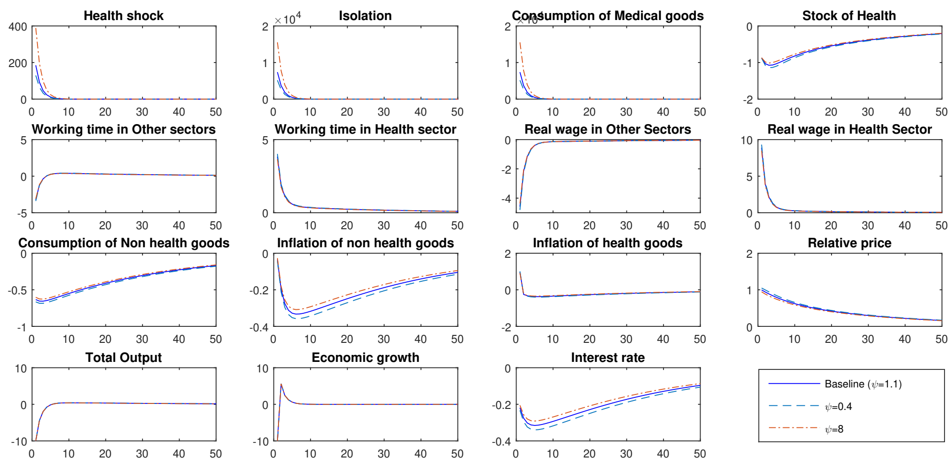

Figure 7: Health shock (sensitivity analysis)

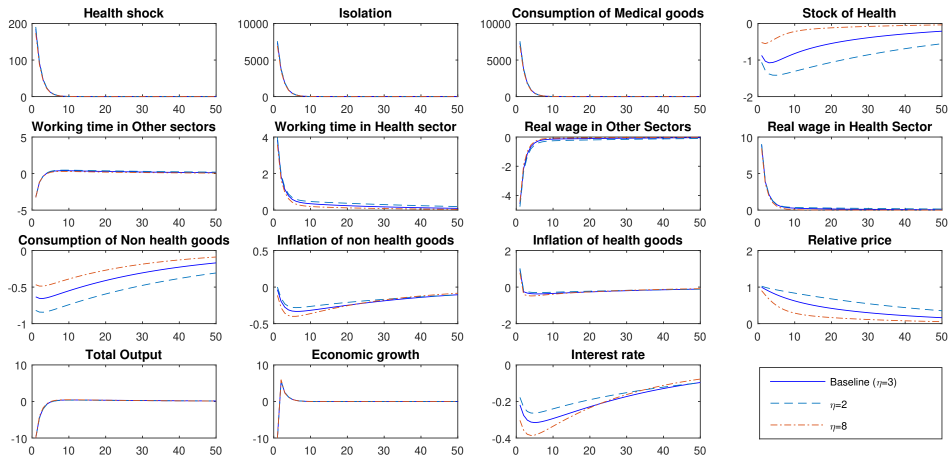

Figure 8: Health shock (sensitivity analysis)

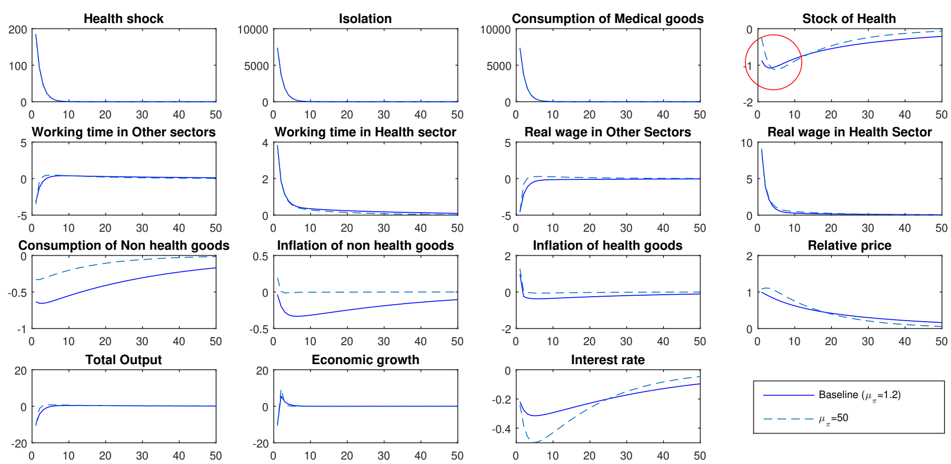

Figure 9: Health shock (sensitivity analysis)