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Modelling the Effects of a Health Shock on the Armenian Economy

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Abstract

This paper extends the closed economy DSGE model in order to evaluate the impact of the coronavirus on the economy. Our model makes it clear that people's decisions to reduce consumption and working hours due to the health crisis lead to an economic recession. As a result, the spread of the virus declines. Expansionary monetary policy decreases the size of GDP decline, but it is costly in terms of public health. This result shows that there is a trade-off between the output loss caused by the epidemic and the health consequences of the 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

As COVID-19 has spread throughout the world, epidemiological models have been widely used to predict the course of the epidemic. While these models are very useful, they do have an important shortcoming: they do not take into account the interaction between the behaviour of economic agents operating in the economy and the shock of the epidemic.

Policymakers certainly appreciate this interaction. For example, in their Financial Times op-ed of 18 March 2020, Ben Bernanke and Janet Yellen write:

"In the near term, public health objectives necessitate people staying home from shopping and work, especially if they are sick or at risk. So production and spending must inevitably decline for a time."

The latest pandemic shock has stimulated a modification of the standard dynamic stochastic general equilibrium (DSGE) models by the incorporation of a health block into them or by the linking of epidemiological models, which enables an understanding of the repercussions of the pandemic shock on the whole economy. A health shock can be interpreted as a negative labor supply shock, because sick people are either less productive, or they do not work at all. On the other hand, an epidemic generates negative shifts in demand for consumption. Taking into account the aforementioned facts, the shock can be considered a mixture of supply and demand shocks (Eichenbaum et al., 2020a).

Eichenbaum et al. (2020b) extend the canonical epidemiological 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, a containment policy, represented by a tax on consumption, deepens the economic crisis, but reduces the number of infections and deaths. Their results indicate the presence of a trade-off between GDP dynamics and the number of deaths.

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

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

Barrios and Hochberg (2020) and Durante et al. (2020) provide evidence that regions with higher civic culture engaged in more voluntary social distancing. For example, Sweden imposed relatively light restrictions. People tend to adopt social distancing when there is a specific incentive to do so in terms of the risk to health and the financial health cost. Maloney and Taskin (2020) also attribute voluntary actions to either fear or a sense of social responsibility.

Adda (2016), using high frequency data from France, finds that, while policies reducing inter-personal contacts such as school closure or the closure of public transport networks reduce disease prevalence, they are not cost effective. These policies would become cost effective for flu epidemics in instances when the death rate is above average.

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

There are also papers that try to understand the optimal policies during a pandemic, both monetary and fiscal. Fornaro and Wolf (2020) study how monetary and fiscal policies can respond to the current pandemic by preventing the economy from falling into stagnation traps following persistent negative shocks to productivity growth. Authors find that monetary policy is likely to be insufficient in mitigating the slump induced by the coronavirus shock. Instead, aggressive fiscal policy interventions to support investment – and more broadly future productivity capacity – can play a key role in sustaining employment and growth.

Bigio et al. (2020) study optimal policies in response to the COVID-19 crisis in a two-sector Keynesian model. They discuss the effectiveness of credit policy versus lump-sum transfers and show that it depends on the extent of borrowing limits. In one extreme, when credit is ample, transfers are ineffective. In the opposite case, when credit is restricted, a credit policy turns ineffective. Hence, in developed economies, with ample credit limits, transfer policies are more likely to be neutral, whereas in emerging economies, with low credit limit, credit subsidy might not have a bite.

The difference in this paper, and its significance, are as follows: first, we model the health stock of a household explicitly and assume that individuals get utility from it (the modelling approach that we use is quite similar to that of

Yagihashi and Du, 2015). At the same time, aggregate productivity is divided into exogenous component and health status. Second, the shock decreases the health stock of the household rather than the level of employment (see Guerrieri et al., 2020).

This paper models the healthcare sector in the propagation of the pandemic shock and attempts to determine the effects of the spread of COVID-19 on economic decisions. In this framework, the role of monetary policy is also important, as coherent policy during the outbreak of a pandemic is a significant issue of concern for policymakers. The model is calibrated to the Armenian economy. Nevertheless, its structure is general and can be applied to other countries as well.

In our paper, we extend the standard closed economy New Keynesian DSGE model by incorporating a health block into it. The health block is introduced into the model via its accumulation process, rather than being modelled explicitly via the SIR model, because the negative health shock in our framework and the increase in the number of infected people in the framework linked with the SIR model affect the economy in the same way and do not differ significantly from each other. There are three main agents: households, firms, and the central bank. The representative household consumes health and non-health goods, supplies labor in health and non-health sectors, and does investment for capital accumulation which is divided into health capital and physical capital accumulation. Firms are divided into two sectors: the health sector and an 'other' sector. They use effective capital and effective labor to produce consumption and investment goods. It should be noted that the effectiveness of labor is measured by the household's health status. The model highlights that expansionary monetary policy during the pandemic shock, in spite of the fact that it stimulates the economy in the short run, promotes the maintenance of a lower level of health stock in that period. In the baseline framework, government is passive and does not intervene at all, because the main objective of the paper is to study the behaviour of economic agents in response to epidemic shock.

The paper then discusses the optimal monetary policy during COVID-19. A committed Ramsey planner minimising the variation of inflation can achieve a very small decline in output and inflation but a huge decline in health status. When the planner also considers health, he or she can achieve a smaller decline in health status and output compared to the case under the Taylor rule. The cost of this is expressed in relatively high inflation. Later, we introduce a government which tries to lessen the negative production externalities from the declining health. The government section is modelled in a simple manner, and we assume that the deficit can be financed from external sources. By comparing the simple rule with the optimal, we find that a committed policy results in a better outcome both in terms of health and economic performance. We also allow government to finance health spending. This allows a gain in health status but creates inflation pressures. Government intervention results in an increase in budget deficit and debt.

The paper also discusses the robustness of the results of the model's different specifications. Firstly, we relax the assumption of the separability of consumption and health in the household's utility function. Secondly, the more general case of health investment, in the form of the constant elasticity of substitution (CES) function with health consumption and isolation, is used to avoid unit elasticity of substitution between them. Then we introduce isolation time to the utility function, removing isolation costs from budget constraints. The responses of the model variables to these three different specifications are in line with the results of the baseline model.

The rest of the paper is organised as follows. Section 2 develops the model. Section 3 illustrates the calibration of the parameters. Section 4 presents the main results of the model, representing the dynamics of the main economic variables in response to the health shock, then it discusses optimal monetary policy and introduces fiscal policy. Section 5 tests the robustness of the model's results with different specifications. Finally, Section 6 concludes.

2 The Model

This section develops the standard set of micro-foundations in the DSGE model, allowing the taking of health and its economic implications into account. The basic structure of the model is as follows. Households receive utility from the consumption of non-health goods, from leisure, and from being healthy. Health status is introduced to the household utility function à la Yagihashi and Du (2015), and it indicates the accumulation of health stock. Differently from their approach, this paper models health investment as a function of medical goods and isolation. Isolation time is produced in the health sector (as e.g. time taken for hospital treatment). The representative household works in the health and non-health sectors, consumes goods which are divided into health and non-health goods, and makes investments in the accumulation of health and non-health capital. Households solve two optimisation problems. Firstly, they minimise their total expenditures and decide how many health and non-health goods to consume. Secondly, they maximise their utility function subject to the budget constraints that balance all sources of income with 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 have access to the government bonds that pay a nominal riskless interest rate. Households also choose the utilisation rate of capital and supply it to domestic firms which produce intermediate goods. Firms in the non-health production sector use 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 goods producers in each sector use the Cobb-Douglas production function. The monetary authority sets the nominal interest rate via the Taylor rule. The schematic representation of the model is captured in Figure 1.

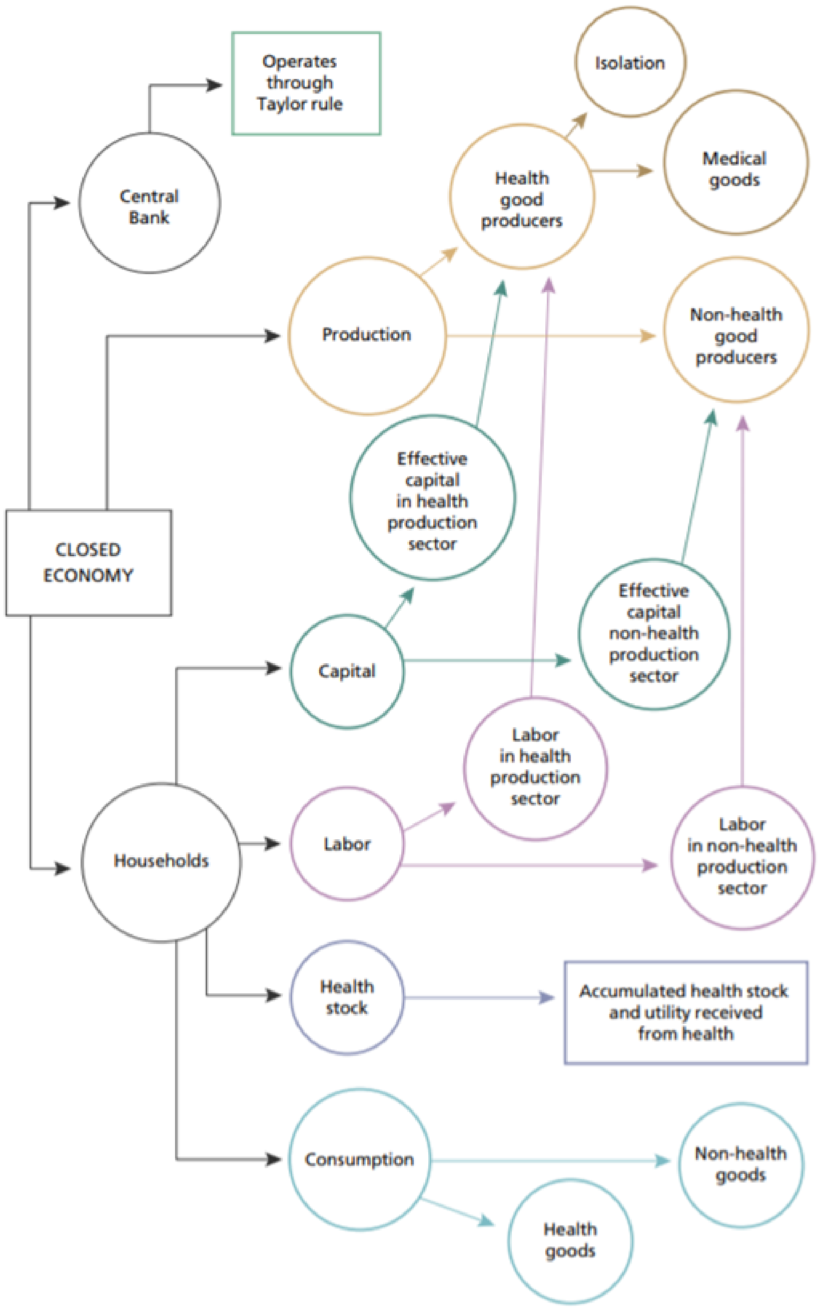


Figure 1: Model Environment

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 respectively the inverse of the intertemporal elasticities of substitution for non-health goods consumption and health status, and ψ is the utility weight on health status.

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

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

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 correspondingly 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, $\frac{W_{N,t}}{P_{H,t}} N_{M,t}$ is the isolation (hours) represented in terms of health 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.

We model health status of the household as a stock, which depreciates 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 spend their time on work in the non-health sector. Consequently, the opportunity cost of self isolation is the real wage in the non-health sector (see Figure 2).

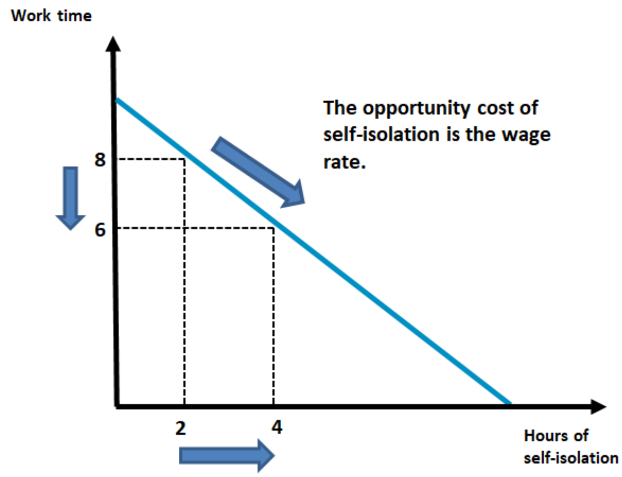


Figure 2: The opportunity cost of the isolation

The occurrence of a health disaster is captured in the following health accumulation equation[1]:

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

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

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 physical 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. This way of modeling the effective capital enables to have a decline in capital during Covid shock.

Following Christiano et al.(2011), this paper uses the functional form of capital utilization given by:

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

[1]We could have isolation without wage in health investment and still obtain our main results. Simulations are available upon request.

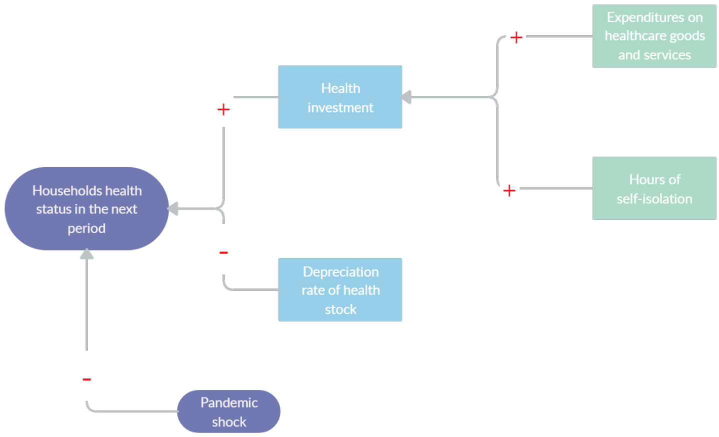


Figure 3: Accumulation of Health Stock

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 (2.1.3), we get the following set of first order conditions:

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

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

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

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

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

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

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

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

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

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

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

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):

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

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:

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

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

Substituting λ_t by $C_{N,t}^{-\sigma}$ in equations (2.1.13) and (2.1.14), capital supply equations get the form:

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

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

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

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

From (2.1.15):

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

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:

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

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

2.2 Firms

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

2.2.1 Health goods production

The intermediate health goods producers operate in monopolistic competitive environment and use Cobb-Douglas production function given as follows:

$$Y_{H,t} = A_{H,t}(K^{eff}_{H,t})^{\alpha_H}(N_{H,t}H_t)^{1-\alpha_H} \tag{2.2.1}$$

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:

$$\frac{r^k_{H,t}}{w^r_{H,t}} = \frac{\alpha_H}{1-\alpha_H}\frac{N_{H,t}}{K^{eff}_{H,t}} \tag{2.2.2}$$

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

$$MC_{H,t} = \left(\frac{r^k_{H,t}}{\alpha_H}\right)^{\alpha_H}\left(\frac{w^r_{H,t}}{1-\alpha_H}\right)^{1-\alpha_H}\frac{1}{A_{H,t}H_t^{1-\alpha_H}}\frac{P_{N,t}}{P_{H,t}} \tag{2.2.3}$$

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

$$x^H_{1,t} = \frac{Y_{H,t}MC_{H,t}}{C^{\sigma}_{N,t}} + \theta_H\beta E_t\Pi^{\varepsilon_H}_{H,t+1}x^H_{1,t+1} \tag{2.2.4}$$

$$x^H_{2,t} = \frac{Y_{H,t}}{C^{\sigma}_{N,t}} + \theta_H\beta E_t\Pi^{\varepsilon_H-1}_{H,t+1}x^H_{2,t+1} \tag{2.2.5}$$

$$\Pi^*_{H,t} = \frac{\varepsilon_H}{\varepsilon_H-1}\Pi_{H,t}\frac{x^H_{1,t}}{x^H_{2,t}} \tag{2.2.6}$$

$$\Pi^{1-\varepsilon_H}_{H,t} = \theta_H + (1-\theta_H)(\Pi^*_{H,t})^{1-\varepsilon_H} \tag{2.2.7}$$

where $x^H_{1,t}$ and $x^H_{2,t}$ are auxiliary variables.

2.2.2 Non-health goods production

The problem for intermediaries in the non-health sector is identical to this in the health care sector.
The production function of intermediate non-health goods is represented by the following Cobb-Douglas function:

$$Y_{N,t} = A_{N,t}(K^{eff}_{N,t})^{\alpha_N}(N_{N,t}H_t)^{1-\alpha_N} \tag{2.2.8}$$

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

$$\frac{r^k_{N,t}}{w^r_{N,t}} = \frac{\alpha_N}{1-\alpha_N}\frac{N_{N,t}}{K^{eff}_{N,t}} \tag{2.2.9}$$

$$MC_{N,t} = \left(\frac{r^k_{N,t}}{\alpha_N}\right)^{\alpha_N}\left(\frac{w^r_{N,t}}{1-\alpha_N}\right)^{1-\alpha_N}\frac{1}{A_{N,t}H_t^{1-\alpha_N}} \tag{2.2.10}$$

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

$$x^N_{1,t} = \frac{Y_{N,t}MC_{N,t}}{C^{\sigma}_{N,t}} + \theta_N\beta E_t\Pi^{\varepsilon_N}_{N,t+1}x^N_{1,t+1} \tag{2.2.11}$$

$$x^N_{2,t} = \frac{Y_{N,t}}{C^{\sigma}_{N,t}} + \theta_N\beta E_t\Pi^{\varepsilon_N-1}_{N,t+1}x^N_{2,t+1} \tag{2.2.12}$$

$$\Pi^*_{N,t} = \frac{\varepsilon_N}{\varepsilon_N-1}\Pi_{N,t}\frac{x^N_{1,t}}{x^N_{2,t}} \tag{2.2.13}$$

$$\Pi^{1-\varepsilon_N}_{N,t} = \theta_N + (1-\theta_N)(\Pi^*_{N,t})^{1-\varepsilon_N} \tag{2.2.14}$$

2.3 Market Clearing Conditions

Output of the health sector is divided into health goods consumption and isolation represented in terms of consumption goods:

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

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

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

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 less willing to work in health sector due to the higher risk of getting infected (the common value of this parameter is 2 (see Christiano et al. (2011)). 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. We have an effective capital equations for each sector and there two parameters (one for each sector) $\gamma_n^N = 4$ and $\gamma_n^H = 1.1$. The latter four parameters are calibrated in a way that in a steady state (see Appendix A) health sector's employment is about 5% (to match Armenian data) and consequently rest are employed in non-health sector.

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 consistent with stylized facts for Armenian economy. Depreciation rates of capitals employed in both sectors δ_H and δ_N are calibrated to common value 0.025 used in DSGE literature (Smets and Wouters (2007), Fernandes-Villaverde (2009)).

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%. Following wide range of literature (Gali and Monacelli (2005), Christiano et al. (2011), etc.), we set ε_H and ε_N (the elasticity of substitution among intermediate goods for health and non-health sector) to 6 implying 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 the response of monetary policy to health shock, and does some sensitivity analysis as well. All the graphs of impulse responses represent time in quarters (horizontal axis) and vertical axis show percentage deviation of variables from steady states[2].

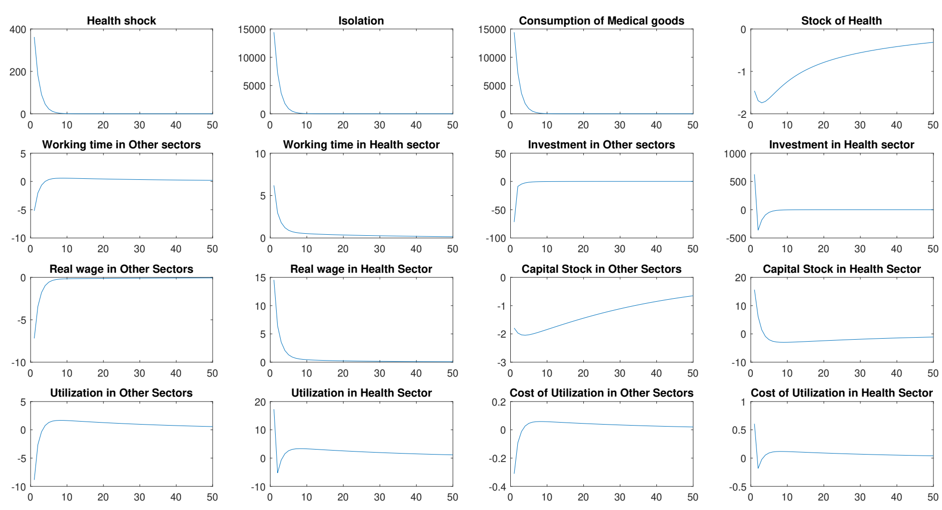
4.1 Impulse responses to health shock

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 match quarter on quarter decline in Armenian GDP growth by 16.2% in the second quarter of 2020.

Negative health shock decreases health status of the households by generating negative health stock. The more hard hits the shock, people become more isolated in order to recover their health status. 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 high demand for labor and decreases in other sectors. As a result, labor increases in health sector and decreases in non-health sector. Increase in medical goods consumption and isolation time lead health stock to recover and converge to its steady state at the end of simulation period. Higher wages in health sector bring marginal costs

[2] The simulations are implemented within the Dynare software platform.

up, which creates inflation. The decrease in real wages in non-health goods sector shrinks marginal costs. Additionally, the effect of the decrease in health stock exceeds the effect of wages, which results in an increase of marginal costs. The reason of higher growth in non-health sector's marginal costs is that in health goods sector marginal costs also depend 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 dynamics restricts the increase of marginal cost in health goods sector. In health sector prices are more flexible and the price elasticity with respect to marginal costs is higher. This creates higher inflation. On the other hand, the presence of higher price stickiness in non-health goods sector prevents inflation and emerges a deflation. 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 sector's investment. 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 its utilization 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. As a growing function of capital stock and utilization of capital, effective capital increases in health sector and declines in other sectors as well. 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. Share of health sector in total GDP is small, which results in a decline of total production due to high decrease in non-health sector. Despite the huge decline in total output, deflation is not so high indicating demand and supply nature of health shock. Monetary authority reacts to deflation and negative output by decreasing interest rate modestly.



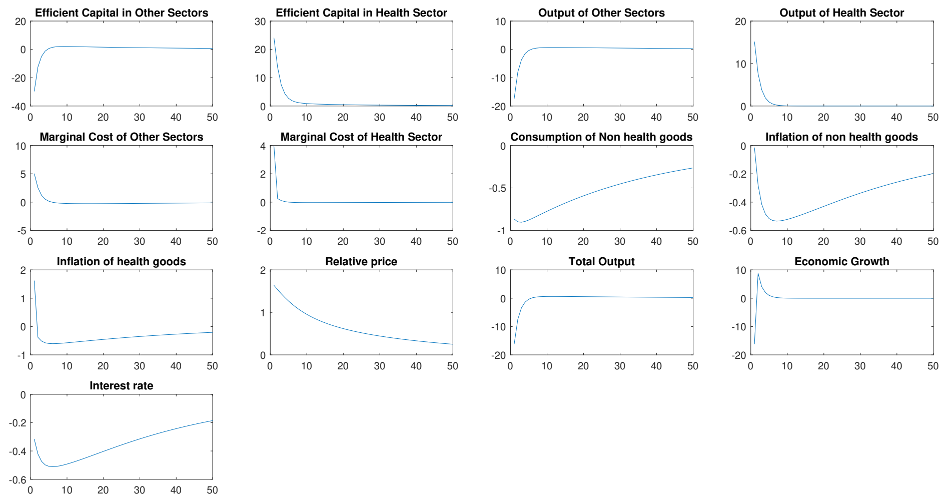


Figure 4: Impulse responses to health shock

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. We check to what extent the impulse response functions of health shock depend on some health related parameters, because there is no evidence on these parameters in the literature. Figure 10 (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. Compared to baseline calibration health stock declines less during the first six quarters and because of high persistence it converges to steady state later. And then we set it to be 0.075 to see the adverse situation. In this case, health stock declines more during the same quarters but converges to steady state faster because of low persistence. The next exercise tests the model sensitivity with respect to health share parameter in household's utility (Figure 11). Applying the same logic as for the depreciation rate we first set it equal to 0.4 and then 8. In case of $\psi = 8$ households value their health status much more compared to baseline case, which results in a less decline of health stock and output. Higher inverse of the intertemporal elasticity of substitution for health status η means that households smooth their health more throughout time leading to the less decline of the latter compared to baseline (Figure 12). The results show that though the size of responses for some variables changes, but the direction and dynamics of this responses remain almost the same.

4.3 Expansionary monetary policy during Covid-19 shock

This section studies the behavior of the economy when Central bank does expansionary monetary policy during the health shock[3]. Results are captured in Figure 5. 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 and decrease the time for isolation. 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, we get a trade-off between the recession severity and the health status of the epidemic similar to results reported in Eichenbaum et al. (2020).

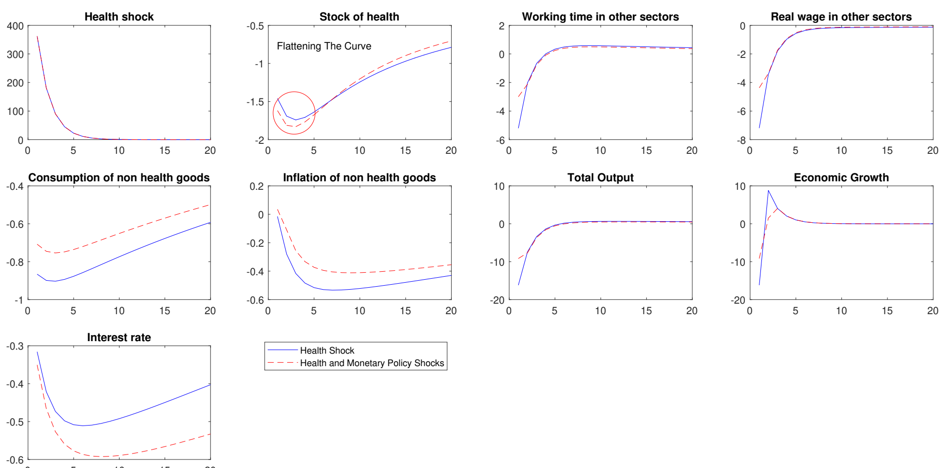


Figure 5: Negative interest rate shock during Covid-19

[3]This exercise is done using Dynare software (simultaneous health and monetary policy shocks).

4.4 Lockdown

To model lockdown, we introduce wedge ξ_t between supply and demand of non-health goods as follows:

$$(1-\xi_t)Y_{N,t} = C_{N,t} + I_{N,t} + I_{H,t} + a(u_{N,t})K_{N,t} + a(u_{H,t})K_{H,t} \tag{4.4.1}$$

Results are presented in Figure 6. As a result of lockdown, economic activity declines leading to the decrease in real wages. Decline in real wages means that opportunity costs of isolation decreases, which motivates households to isolate more. This entails in modest decline of health stock. In contrast, total output declines more, which indicates the trade-off between output and health. In reality, targeted policies conducted by authorities may result a better performance in terms of both economic and health outcomes. This can be achieved by closing or restricting sectors with high probability of getting infected and stimulating other sectors by aggregate expansionary or targeted policy. These kind of policies are out of scope of this paper.

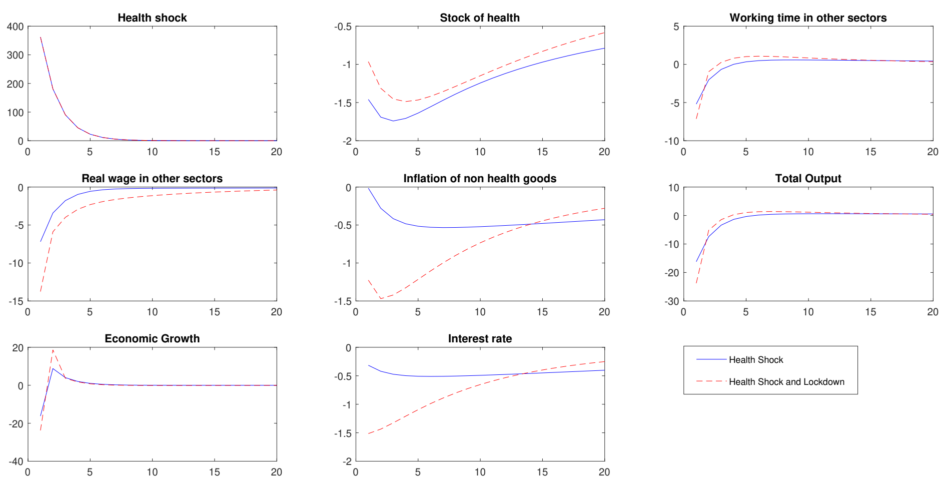


Figure 6: Lockdown during Covid-19

4.5 Optimal monetary policy

This subsection applies optimal monetary policy rule to minimize welfare loses created by health shock. Ramsey planner in our economy minimizes quadratic deviations of non-health inflation and health stock from their steady state having the following objective function.

$$E_t \sum_{j=0}^{\infty} \beta^j \left[(\pi_{N,t+j} - \pi_N^{ss})^2 + w(H_{t+j} - H^{ss})^2 \right] \rightarrow min \tag{4.5.1}$$

In equation (4.5.1) w is the relative weight of health in the planner's objective function. Ramsey planner has interest rate as a policy instrument. For the optimal policy, we have two cases. First one takes into account only inflation and ignores health ($w = 0$), while the second one cares more about health ($w = 2$). Figure 7 compares the mentioned two simulations under optimal monetary policy with the baseline one when interest rate follows Taylor rule. When the policymaker cares only about inflation, he or she is able to smooth its variation by committing to keep interest rate close to zero (blue dashed line). This results in a decrease of health status compared to the baseline case. By introducing the health variation in the planner's objective function, one should care more about the health dynamics and increases interest rate to prevent the further decline of health status (red dash-dotted line). The latter results in a higher decline of output compared to the case without health in objective function. Results of simulation show, that central bank is able to conduct a beneficial policy both in terms of health and output, but have a little costly inflation. But in reality it is impossible to run fully committed policy, especially in developing countries.

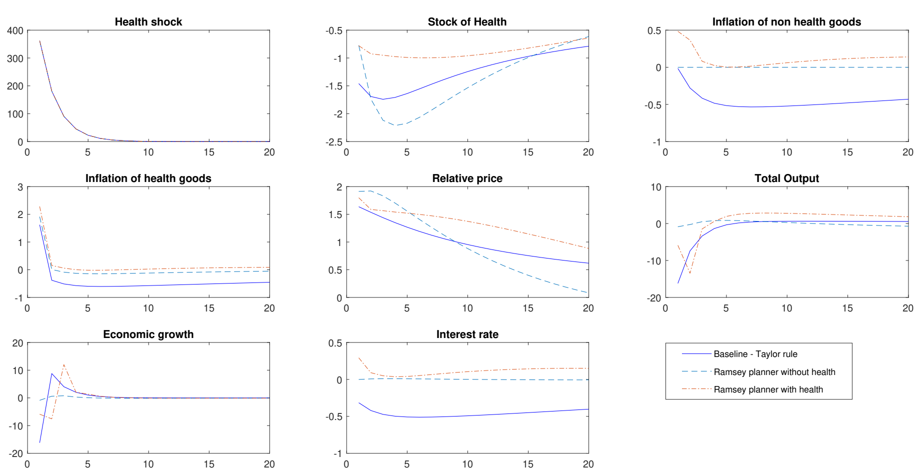


Figure 7: Optimal monetary policy during Covid-19

4.6 Fiscal policy

This subsection extends the model by introducing government policy into the model in a simple manner to test the effectiveness of fiscal policy in a response to epidemic shock. We do not derive the government problem from micro foundations and assume, that government uses external borrowing to subsidize the economy.

As the model assumes health externality on production, government subsidizes firms to neutralize the negative effects health status has on production. Here government acts with a subsidy in the production function given by the following.

$$Y_{i,t} = A_{i,t}(K_{i,t}^{eff})^{\alpha_i}(N_{i,t}H_t\tau_t)^{1-\alpha_N} \quad i = H, N \tag{4.6.1}$$

Solution of the firms problems give marginal costs functions, where we have the same subsidy both for non-health and health firms.

$$MC_{H,t} = \left(\frac{r_{H,t}^k}{\alpha_H}\right)^{\alpha_H}\left(\frac{w_{H,t}^r}{1-\alpha_H}\right)^{1-\alpha_H}\frac{1}{A_{H,t}(H_t\tau_t)^{1-\alpha_H}}\frac{P_{N,t}}{P_{H,t}} \tag{4.6.2}$$

$$MC_{N,t} = \left(\frac{r_{N,t}^k}{\alpha_N}\right)^{\alpha_N}\left(\frac{w_{N,t}^r}{1-\alpha_N}\right)^{1-\alpha_N}\frac{1}{A_{N,t}(H_t\tau_t)^{1-\alpha_N}} \tag{4.6.3}$$

Next we define the simple fiscal rule, which authorities use to neutralize the negative externality health has on the production represented by the following.

$$\tau_t = \frac{1}{H_t} \tag{4.6.4}$$

Figure 8 shows results of the simulation. Simple fiscal rule results in a less decline of production (blue dashed line) compared to the baseline case without fiscal policy (solid blue line). In contrast to this, direct fiscal support of production results in a deep decline of health status, because higher wages in the economy make isolation costly for households. Then the planner keeps the production subsidy and chooses the path of it to minimize variations of economic growth and health represented by the following objective.

$$E_t\sum_{j=0}^{\infty}\beta^j\left[0.5\left(\frac{y_{t+j}}{y_{t+j-1}}-1\right)^2+(H_{t+j}-H^{ss})^2\right]\rightarrow min \tag{4.6.5}$$

Ramsey optimizer gives 0.5 weight to economic growth and unit weight to health status. Red dash-dotted line in figure 8 represents results. Committed planner is able to benefit in terms of health status and economic growth by providing huge amount of subsidy to production, which results in an higher increase of budget deficit. This policy creates inflation, and monetary authority increases interest rate to bring it back to the target. In reality, government has constraint to extend it's budget deficit, that's why we introduce some constraint on budget deficit to the 5 % in GDP to have a more realistic simulation (green dotted line). Financially constrained government still prevents the high decline in health stock compared to the simple rule, but it performs worse than the unconstrained Ramsey planner.

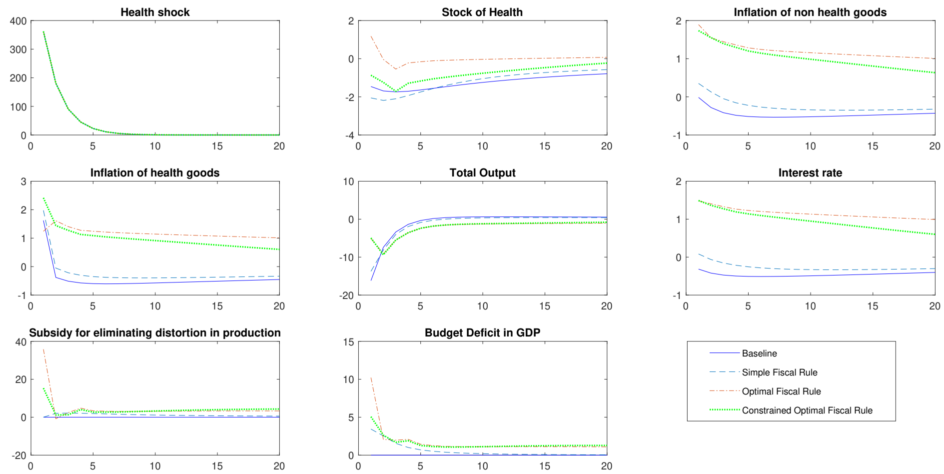


Figure 8: Government subsidy to production during Covid-19

In a lot of the countries around the globe, governments finance healthcare costs of people with Covid. The rest of this section introduces government financing of health into the model and estimates its impact on the economy and health status during the pandemic. The government acts in the model by the subsidy on health firms marginal costs, which decreases production costs of health firms making them more competitive compared to the non-health sector. To recover the loss of non-health sector as a result of becoming less competitive, government also finances non-health production. We have the same subsidy in the following two equations of the model.

$$MC_{H,t} = \left(\frac{r^k_{H,t}}{\alpha_H}\right)^{\alpha_H} \left(\frac{w^r_{H,t}}{1-\alpha_H}\right)^{1-\alpha_H} \frac{1}{A_{H,t} H_t^{1-\alpha_H}} \frac{P_{N,t}}{P_{H,t}} \left(\frac{1}{\tau_t}\right)^{\omega_1} \tag{4.6.6}$$

$$Y_{N,t}\tau_t^{\omega_2} = C_{N,t} + I_{N,t} + I_{H,t} + a(u_{N,t})K_{N,t} + a(u_{H,t})K_{H,t} \tag{4.6.7}$$

Where ω_1 and ω_2 are sensitivity parameters. Fiscal authority follows a simple rule by subsidizing the economy as long as Covid shock exists.

$$\tau_t = c \times \varepsilon_t^{covid-19} \quad (c = constant) \tag{4.6.8}$$

Paper discusses also optimal rule, which maximizes (4.6.5) objective function. Results are captured in Figure 9. Applying simple fiscal rule (blue dashed line), government prevents from the longer low value of health stock compared to the baseline. It finances the other sector as well, creating a huge budget deficit. On the other hand, committed planner reduces the volatility of health stock significantly and supports economic activity, which creates inflationary pressures. Planner committed to minimize volatility of economic growth and health stock is able to do that by lower budget deficit compared with the simple rule, but has a small positive deficit throughout the whole period of simulation.

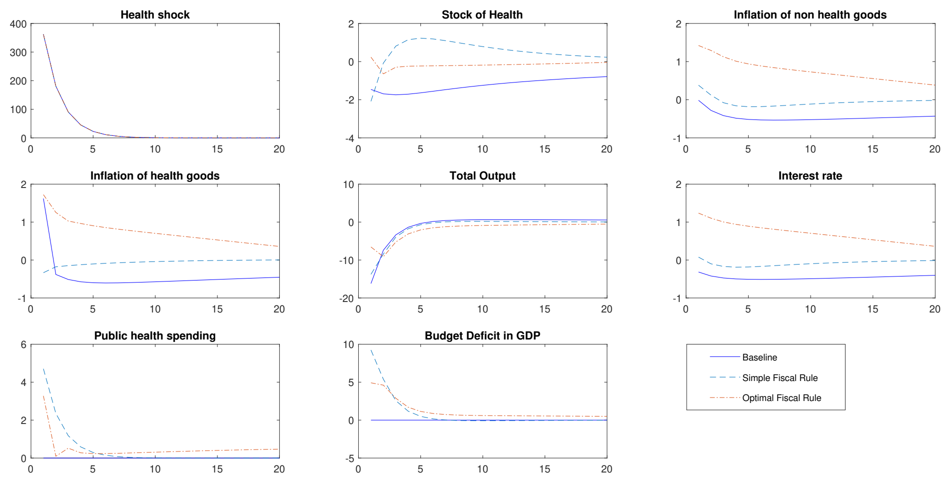


Figure 9: Public health spending during Covid-19

5 Robustness

This section checks the robustness of results to different specifications of the model. The first exercise changes separable utility function into non-separable with consumption and health status represented by the following equation.

$$E_t \sum_{j=0}^{\infty} \beta^j \left(\frac{(C_{N,t+j}^{\phi} H_{t+j}^{1-\phi})^{1-\sigma}}{1-\sigma} - \chi_N \frac{N_{N,t+j}^{1+\varphi_N}}{1+\varphi_N} - \chi_H \frac{N_{H,t+j}^{1+\varphi_H}}{1+\varphi_H} \right) \tag{5.0.1}$$

Hall and Jones (2007) says the following:

"However, even the direction of the effect is unclear: Is the marginal utility of consumption higher or lower for sick people? One can easily think of reasons why it might be lower. On the other hand, the marginal utility of having a personal assistant or of staying in a nice hotel with lots of amenities might actually be higher for people with a lower health status. Our separability assumption can be viewed as a natural intermediate case"

Figure 13 in Appendix E plots results of robustness exercise with respect to separability/non-separability of consumption and health in utility function. Relaxing assumption of separability, we obtain our main results.

Paper discusses investment in health as a Cobb-Douglas function of health consumption and isolation. Now we relax this assumption by introducing CES function and avoid the unit elasticity of substitution between these inputs.

$$H_{t+1} = (1-\delta_h)H_t + \left[\alpha_h C_{H,t}^{1-\nu} + (1-\alpha_h) \left(\frac{W_{N,t}}{P_{H,t}} N_{M,t} \right)^{1-\nu} \right]^{\frac{1}{1-\nu}} \tag{5.0.2}$$

Where ν is the elasticity of substitution. We then test the robustness of results with respect to critical values ($\nu = 90$ and $\nu = 0.005$) of the elasticity. As demonstrated in the Figure 14 in Appendix E, results are quite robust and don't differ significantly from the baseline.

In the last robustness exercise we add disutility from isolation time into utility function, similarly to disutility from labor and remove it from budget constraint:

$$E_t \sum_{j=0}^{\infty} \beta^j \left(\frac{C_{N,t+j}^{1-\sigma}}{1-\sigma} - \chi_N \frac{N_{N,t+j}^{1+\varphi_N}}{1+\varphi_N} - \chi_H \frac{N_{H,t+j}^{1+\varphi_H}}{1+\varphi_H} - \chi_M \frac{N_{M,t+j}^{1+\varphi_M}}{1+\varphi_M} + \psi \frac{H_{t+j}^{1-\eta}}{1-\eta} \right) \tag{5.0.3}$$

We construct this model with and without real wage in the health accumulation equation and as one can see in Figure 15 (Appendix E), directions of main variables are the same as those of main specification.

6 Conclusion

This paper incorporates 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 health shock, which embodies the outbreak of COVID-19 pandemic in the economy. We obtain that epidemic shock leads to the cut of non-health goods consumption and production. Shock results in a modest decline in inflation and a policymaker acting with Taylor rule decreases interest rate.

Paper analyzes 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 conditions, 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 activity and health consequences caused by epidemic. Results are in line with results obtained by Eichenbaum et al. (2020).

Then the paper discusses optimal monetary policy in times of pandemic. We find, that planner is able to prevent huge decline in health stock and output, but creates some inflation. Furthermore, simple government with subsidies is introduced in an ad-hoc manner. First, it tries to correct distortions in the production arising from the decrease of health status. Committed planner acts in a way to prevent the health decline and results in a less decline of output. This generates budget deficit for about 10 % in terms of GDP. But this policy creates some inflation and central bank increases interest rate. If government has constraint on budget deficit, health declines more compared to the simulation with unconstrained government. Second, government expands health sector by budget financing. This simulation shows, that such type of policy is beneficial for the economy and health developments, but leads to the increase in budget deficit. Paper does some robustness analysis as well. Our main results are consistent with different specifications of the model.

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

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

It would be interesting to introduce a micro-founded government into the model, with its aggregate and sector-specific tools to perceive the optimal policy response to stabilise a health crisis.

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7 Appendix

7.1 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:

$$a(u_H) = 0 \tag{7.1.1}$$

$$a(u_N) = 0 \tag{7.1.2}$$

and the follwoing variables are equal to one:

$$A_H = 1 \tag{7.1.3}$$

$$A_N = 1 \tag{7.1.4}$$

$$u_H = 1 \tag{7.1.5}$$

$$u_N = 1 \tag{7.1.6}$$

$$H = 1 \tag{7.1.7}$$

$$\frac{P_H}{P_N} = 1 \tag{7.1.8}$$

$$\Pi_H = \Pi_N = \Pi_H^* = \Pi_N^* = 1 \tag{7.1.9}$$

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

$$\Phi_N = Y_{N,t} - C_{N,t} - I_{N,t} - I_{H,t} \tag{7.1.10}$$

$$\Phi_H = Y_{H,t} - C_{H,t} - \frac{W_{N,t}}{P_{H,t}} N_{M,t} \tag{7.1.11}$$

$$\gamma_m^N = \frac{1}{N_N^{\gamma_n^N}} \tag{7.1.12}$$

$$\gamma_m^H = \frac{1}{N_H^{\gamma_n^H}} \tag{7.1.13}$$

$$\xi_b = r_N^K \tag{7.1.14}$$

$$\xi_n = r_H^K \tag{7.1.15}$$

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

$$MC_H = \frac{\varepsilon_H - 1}{\varepsilon_H} \tag{7.1.16}$$

$$MC_N = \frac{\varepsilon_N - 1}{\varepsilon_N} \tag{7.1.17}$$

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

$$R = \frac{1}{\beta} \tag{7.1.18}$$

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:

$$r^K_N = \frac{1}{\beta} - (1 - \delta_N) \tag{7.1.19}$$

$$r^K_H = \frac{1}{\beta} - (1 - \delta_H) \tag{7.1.20}$$

From (2.2.4) and (2.2.11):

$$w_N = MC_N(\alpha_N)^{\alpha_N}(1 - \alpha_N)^{1-\alpha_N}\left(\frac{1}{r^K_N}\right)^{\alpha_N} \tag{7.1.21}$$

$$w_H = MC_H(\alpha_H)^{\alpha_H}(1 - \alpha_H)^{1-\alpha_H}\left(\frac{1}{r^K_H}\right)^{\alpha_H} \tag{7.1.22}$$

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

$$C_N = \left[\left(\frac{1}{\beta\alpha_h}\left(\frac{\alpha_h}{1-\alpha}\right)^{1-\alpha_h} - \left(\frac{\alpha_h}{1-\alpha}\right)^{1-\alpha_h}\frac{(1-\delta_h)}{\alpha_h}\right)\frac{1}{\psi}\right]^{\frac{1}{\sigma}} \tag{7.1.23}$$

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

$$N_N = \left[(w_N + \gamma^N_n \frac{\alpha_N}{1-\alpha_N} w_N)\frac{1}{\chi_N}\frac{1}{C^\sigma_N}\right]^{\frac{1}{\varphi_N}} \tag{7.1.24}$$

$$N_H = \left[(w_H + \gamma^H_n \frac{\alpha_H}{1-\alpha_H} w_H)\frac{1}{\chi_H}\frac{1}{C^\sigma_N}\right]^{\frac{1}{\varphi_H}} \tag{7.1.25}$$

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

$$K_N = \frac{\alpha_N}{1-\alpha_N}\frac{w_N}{r^K_N}N_N \tag{7.1.26}$$

$$K_H = \frac{\alpha_H}{1-\alpha_H}\frac{w_H}{r^K_H}N_H \tag{7.1.27}$$

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

$$C_H = \delta_h\left(\frac{\alpha_h}{1-\alpha_h}\right)^{1-\alpha_h} \tag{7.1.28}$$

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

$$N_M = \frac{1-\alpha_h}{\alpha_h} C_H \frac{1}{w_N} \tag{7.1.29}$$

$$K_N^{eff} = K_N \tag{7.1.30}$$

$$K_H^{eff} = K_H \tag{7.1.31}$$

$$Y_H = N_H^{1-\alpha_H} K_H^{\alpha_H} \tag{7.1.32}$$

$$Y_N = N_N^{1-\alpha_N} K_N^{\alpha_N} \tag{7.1.33}$$

$$I_H = \delta_H K_H \tag{7.1.34}$$

$$I_N = \delta_N K_N \tag{7.1.35}$$

$$x_1^H = \frac{1}{C_N^{\sigma}} \frac{Y_H MC_H}{1-\theta\beta(\Pi_H)_H^{\varepsilon}} \tag{7.1.36}$$

$$x_2^H = \frac{1}{C_N^{\sigma}} \frac{Y_H}{1-\theta\beta(\Pi_H)^{\varepsilon_H - 1}} \tag{7.1.37}$$

$$x_1^N = \frac{1}{C_N^{\sigma}} \frac{Y_N MC_N}{1-\theta\beta(\Pi_N)_N^{\varepsilon}} \tag{7.1.38}$$

$$x_2^N = \frac{1}{C_N^{\sigma}} \frac{Y_N}{1-\theta\beta(\Pi_N)^{\varepsilon_N - 1}} \tag{7.1.39}$$

7.2 Appendix B. Model equations

1. Euler equation

$$C_{N,t}^{\sigma} = \frac{1}{\beta} E_t C_{N,t+1}^{\sigma} \Pi_{N,t+1} R_t^{-1} \tag{7.2.1}$$

2. Labor supply in non-health sector

$$\chi_N N_{N,t}^{\varphi_N} C_{N,t}^{\sigma} = \frac{W_{N,t}}{P_{N,t}} + u_{N,t} \gamma_m^N \gamma_n^N N_{N,t}^{\gamma_n^N - 1} \frac{K_{N,t} R_{N,t}^k}{P_{N,t}} \tag{7.2.2}$$

3. Labor supply in health sector

$$\chi_H N_{H,t}^{\varphi_H} C_{N,t}^{\sigma} = \frac{W_{H,t}}{P_{N,t}} + u_{H,t} \gamma_m^H \gamma_n^H N_{H,t}^{\gamma_n^H - 1} \frac{K_{H,t} R_{H,t}^k}{P_{N,t}} \tag{7.2.3}$$

4. Capital supply in non-health sector

$$\beta E_t \left(\frac{C_{N,t}}{C_{N,t+1}} \right)^{\sigma} \left((u_{N,t+1} \gamma_m^N N_{N,t+1}^{\gamma_n^N}) \frac{R_{N,t+1}^K}{P_{N,t+1}} + (1 - \delta_N - a(u_{N,t+1})) \right) = 1 \tag{7.2.4}$$

5. Capital supply in health sector

$$\beta E_t \left(\frac{C_{N,t}}{C_{N,t+1}} \right)^{\sigma} \left((u_{H,t+1} \gamma_m^H N_{H,t+1}^{\gamma_n^H}) \frac{R_{H,t+1}^K}{P_{N,t+1}} + (1 - \delta_H - a(u_{H,t+1})) \right) = 1 \tag{7.2.5}$$

6. Health care time decision

$$\frac{W_{N,t}}{P_{H,t}} N_{M,t} = \frac{1 - \alpha_h}{\alpha_h} C_{H,t} \tag{7.2.6}$$

7. Health investment decision

$$\beta E_t \left(\psi H_{t+1}^{-\eta} + \left(\frac{C_{H,t+1}}{\frac{W_{N,t+1}}{P_{H,t+1}} N_{M,t+1}} \right)^{1-\alpha_h} \frac{1}{\alpha_h} \frac{P_{H,t+1}}{P_{N,t+1}} \frac{1-\delta_h}{C_{N,t+1}^{\sigma}} \right) = \left(\frac{C_{H,t}}{\frac{W_{N,t}}{P_{H,t}} N_{M,t}} \right)^{1-\alpha_h} \frac{1}{\alpha_h} \frac{P_{H,t}}{P_{N,t}} \frac{1}{C_{N,t}^{\sigma}} \tag{7.2.7}$$

8. Non-health capital utilization decision

$$\xi_m \xi_n u_{N,t} + \xi_n (1 - \xi_m) = \gamma_m^N N_{N,t}^{\gamma_n^N} \frac{R_{N,t}^K}{P_{N,t}} \tag{7.2.8}$$

9. Health capital utilization decision

$$\xi_a \xi_b u_{H,t} + \xi_b (1 - \xi_a) = \gamma_m^H N_{H,t}^{\gamma_n^H} \frac{R_{H,t}^K}{P_{N,t}} \tag{7.2.9}$$

10. Health accumulation

$$H_{t+1} = (1 - \delta_h) H_t + C_{H,t}^{\alpha_h} \left(\frac{W_{N,t}}{P_{H,t}} N_{M,t} \right)^{1-\alpha_h} - \varepsilon_t^{covid-19} \tag{7.2.10}$$

11. Health capital's law of motion

$$K_{H,t+1} = (1 - \delta_H)K_{H,t} + I_{H,t} \tag{7.2.11}$$

12. Non-health capital's law of motion

$$K_{N,t+1} = (1 - \delta_N)K_{N,t} + I_{N,t} \tag{7.2.12}$$

13. Effective non-health capital

$$K^{eff}_{N,t} = \gamma^N_m K_{N,t} u_{N,t} N^{\gamma^N_n}_{N,t} \tag{7.2.13}$$

14. Effective health capital

$$K^{eff}_{H,t} = \gamma^H_m K_{H,t} u_{H,t} N^{\gamma^H_n}_{H,t} \tag{7.2.14}$$

15. Health capital utilization cost

$$a(u_{H,t}) = \frac{1}{2}\xi_a \xi_b u^2_{H,t} + \xi_b(1 - \xi_a)u_{H,t} + \xi_b(\frac{\xi_a}{2} - 1) \tag{7.2.15}$$

16. Non-health capital utilization cost

$$a(u_{N,t}) = \frac{1}{2}\xi_m \xi_n u^2_{N,t} + \xi_n(1 - \xi_m)u_{N,t} + \xi_n(\frac{\xi_m}{2} - 1) \tag{7.2.16}$$

17. Relative price

$$\frac{S_t}{S_{t-1}} = \frac{\Pi_{H,t}}{\Pi_{N,t}} \tag{7.2.17}$$

18. Health firms' production function

$$Y_{H,t} = A_{H,t}(K^{eff}_{H,t})^{\alpha_H}(N_{H,t}H_t)^{1-\alpha_H} \tag{7.2.18}$$

19. Non-health firms' production function

$$Y_{N,t} = A_{N,t}(K^{eff}_{N,t})^{\alpha_N}(N_{N,t}H_t)^{1-\alpha_N} \tag{7.2.19}$$

20. Optimal allocation of resources in health sector

$$\frac{r^k_{H,t}}{w^r_{H,t}} = \frac{\alpha_H}{1 - \alpha_H}\frac{N_{H,t}}{K^{eff}_{H,t}} \tag{7.2.20}$$

21. Optimal allocation of resources in non-health sector

$$\frac{r^k_{N,t}}{w^r_{N,t}} = \frac{\alpha_N}{1 - \alpha_N}\frac{N_{N,t}}{K^{eff}_{N,t}} \tag{7.2.21}$$

22. Real marginal cost of health firms

$$MC_{H,t} = \left(\frac{r^k_{H,t}}{\alpha_H}\right)^{\alpha_H}\left(\frac{w^r_{H,t}}{1 - \alpha_H}\right)^{1-\alpha_H}\frac{1}{A_{H,t}H^{1-\alpha_H}_t}\frac{1}{S_t} \tag{7.2.22}$$

23. Real marginal cost of non-health firms

$$MC_{N,t} = \left(\frac{r^k_{N,t}}{\alpha_N}\right)^{\alpha_N} \left(\frac{w^r_{N,t}}{1-\alpha_N}\right)^{1-\alpha_N} \frac{1}{A_{N,t}H_t^{1-\alpha_N}} \tag{7.2.23}$$

24. First auxiliary variable of health goods Phillips curve

$$x^H_{1,t} = \frac{Y_{H,t}MC_{H,t}}{C^\sigma_{N,t}} + \theta_H \beta E_t \Pi^{\varepsilon_H}_{H,t+1} x^H_{1,t+1} \tag{7.2.24}$$

25. Second auxiliary variable of health goods Phillips curve

$$x^H_{2,t} = \frac{Y_{H,t}}{C^\sigma_{N,t}} + \theta_H \beta E_t \Pi^{\varepsilon_H - 1}_{H,t+1} x^H_{2,t+1} \tag{7.2.25}$$

26. Optimal inflation of health goods

$$\Pi^*_{H,t} = \frac{\varepsilon_H}{\varepsilon_H - 1} \Pi_{H,t} \frac{x^H_{1,t}}{x^H_{2,t}} \tag{7.2.26}$$

27. The aggregate inflation dynamics of health goods

$$\Pi^{1-\varepsilon_H}_{H,t} = \theta_H + (1-\theta_H)(\Pi^*_{H,t})^{1-\varepsilon_H} \tag{7.2.27}$$

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

$$x^N_{1,t} = \frac{Y_{N,t}MC_{N,t}}{C^\sigma_{N,t}} + \theta_N \beta E_t \Pi^{\varepsilon_N}_{N,t+1} x^N_{1,t+1} \tag{7.2.28}$$

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

$$x^N_{2,t} = \frac{Y_{N,t}}{C^\sigma_{N,t}} + \theta_N \beta E_t \Pi^{\varepsilon_N - 1}_{N,t+1} x^N_{2,t+1} \tag{7.2.29}$$

30. Optimal inflation of non-health goods

$$\Pi^*_{N,t} = \frac{\varepsilon_N}{\varepsilon_N - 1} \Pi_{N,t} \frac{x^N_{1,t}}{x^N_{2,t}} \tag{7.2.30}$$

31. The aggregate inflation dynamics of non-health goods

$$\Pi^{1-\varepsilon_N}_{N,t} = \theta_N + (1-\theta_N)(\Pi^*_{N,t})^{1-\varepsilon_N} \tag{7.2.31}$$

32. Market clearing condition of health sector

$$Y_{H,t} = C_{H,t} + \frac{W_{N,t}}{P_{H,t}} N_{M,t} - \Phi_H \tag{7.2.32}$$

33. Market clearing condition of non-health sector

$$Y_{N,t} = C_{N,t} + I_{N,t} + I_{H,t} + a(u_{N,t})K_{N,t} + a(u_{H,t})K_{H,t} - \Phi_N \tag{7.2.33}$$

34. Taylor rule

$$R_t = \left(\frac{R_{t-1}}{R^{ss}}\right)^{\rho_r} \left\{ \left(\frac{E_t \Pi_{N,t+1}}{\Pi_N^{ss}}\right)^{\mu_\pi} \left(\frac{Y_{N,t} + Y_{H,t}}{Y_N^{ss} + Y_H^{ss}}\right)^{\mu_y} \right\}^{(1-\rho_r)} \tag{7.2.34}$$

35. Productivity of non-health goods

$$A_{N,t} = \rho_{a_N} A_{N,t-1} + (1 - \rho_{a_N}) A_N^{ss} + \sigma_{a_N,t} \tag{7.2.35}$$

36. Productivity of health goods

$$A_{H,t} = \rho_{a_H} A_{H,t-1} + (1 - \rho_{a_H}) A_H^{ss} + \sigma_{a_H,t} \tag{7.2.36}$$

37.Health shock

$$\varepsilon_t^{covid-19} = \rho_h \varepsilon_{t-1}^{covid-19} + \sigma_{h,t} \tag{7.2.37}$$

7.3 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	0.025
δ_H	Depreciation rate of capital in health production sector	0.025
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
χ_N	Disutility coefficient of labor supply in non-health sector	2
χ_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	6
ξ_a	Parameter in capital utilization of health capital	0.2
ξ_m	Parameter in capital utilization of non-health capital	0.4
γ_n^H	Parameter in health sector's effective capital equation	1.1
γ_n^N	Parameter in non-health sector's effective capital equation	4

Table 1: Calibration

7.4 Appendix D. Sensitivity Analysis

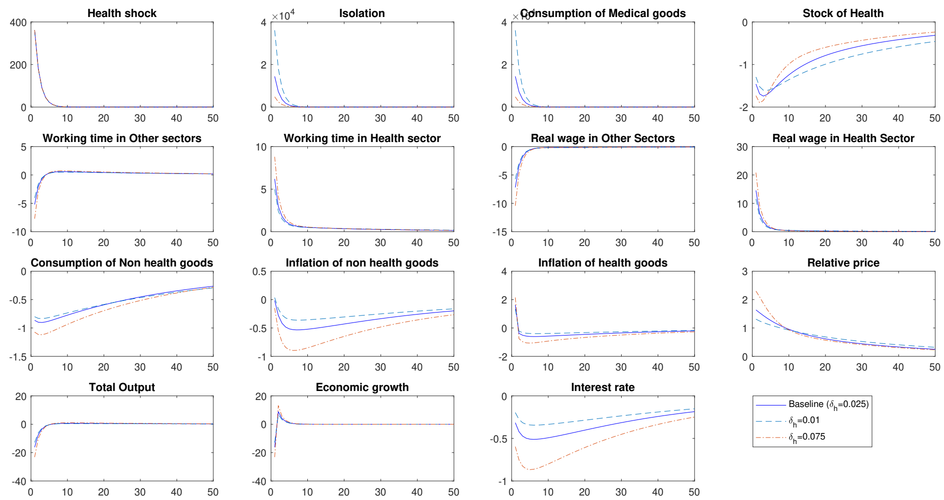

Figure 10: Health shock (Sensitivity analysis with respect to health depreciation rate)

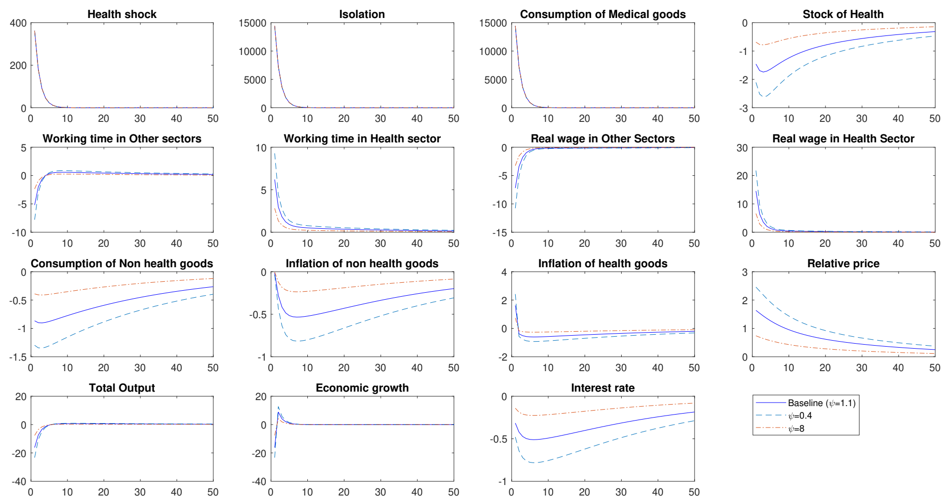

Figure 11: Health shock (sensitivity analysis with respect to health share parameter in household's utility)

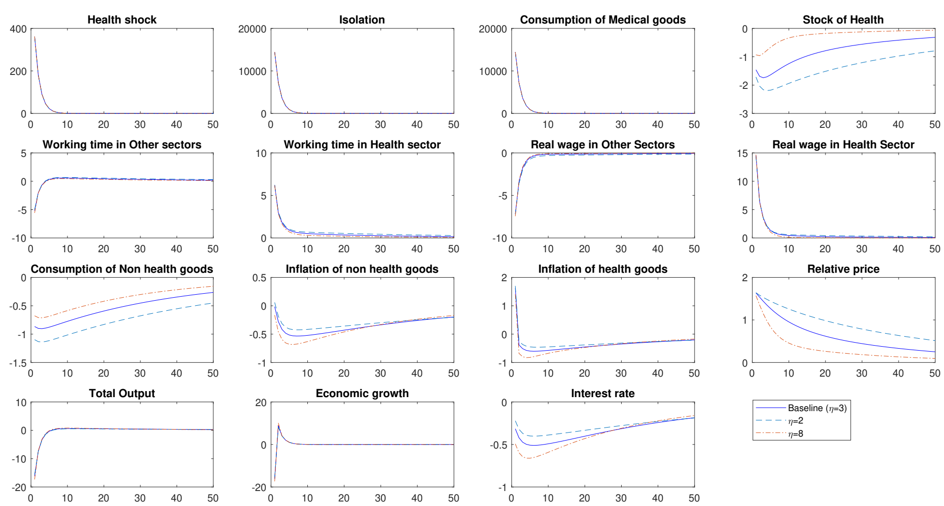

Figure 12: Health shock (sensitivity analysis with respect to the inverse of intertemporal elasticity of substitution for health status)

7.5 Appendix E. Robustness Check

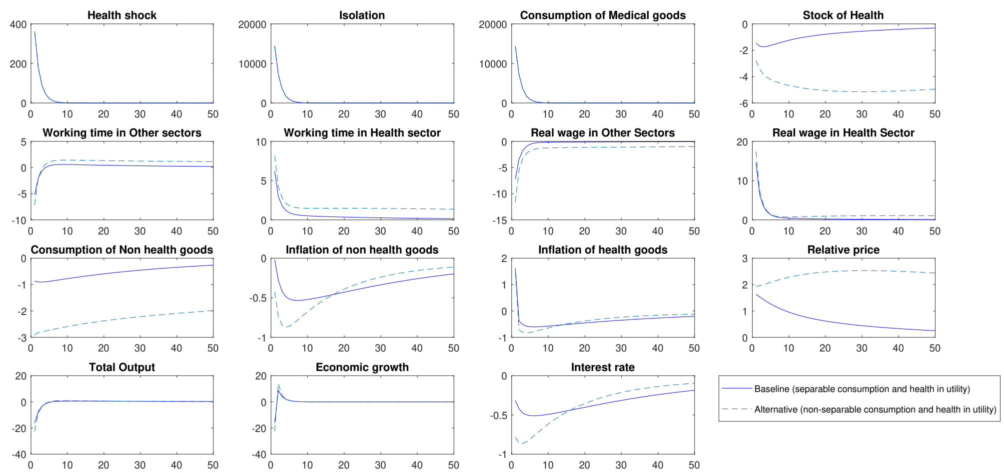

Figure 13: Health shock (Robustness exercise with respect to separability/non-separability of consumption and health)

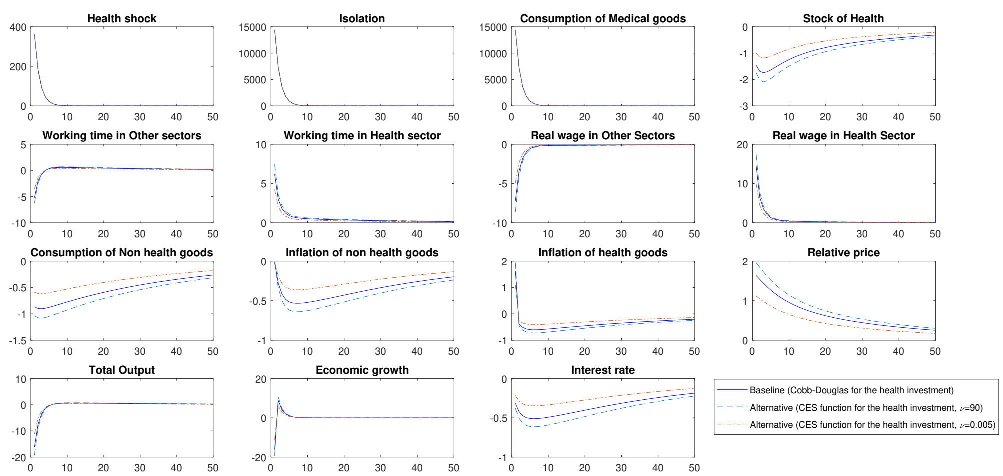

Figure 14: Health shock (Robustness exercise with respect to health investment)

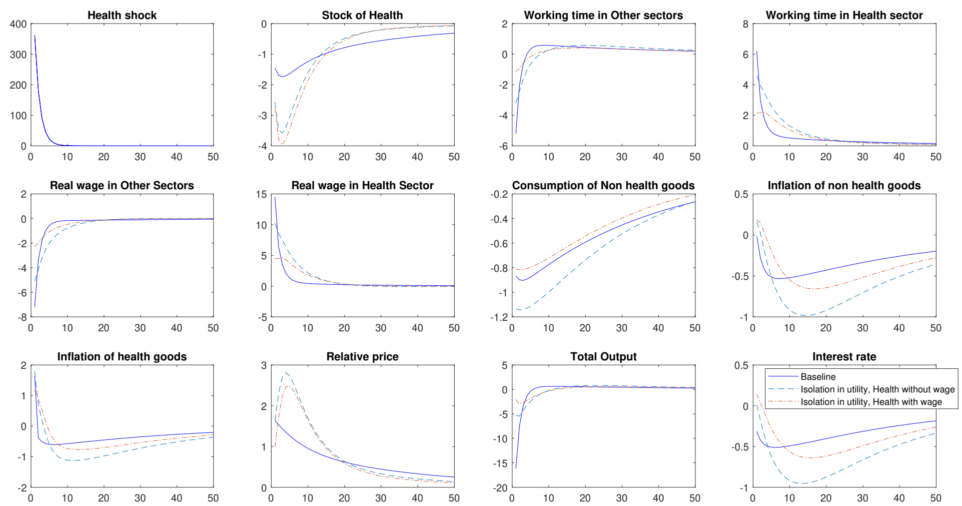

Figure 15: Health shock (Robustness exercise with respect to isolation)