The COVID-19 pandemic: shocks to human capital and policy responses

Guichuan Deng\textsuperscript{a}, Jing Shi\textsuperscript{b,c}, Yanli Li\textsuperscript{d}, Yin Liao\textsuperscript{c}

\textsuperscript{a}International School of Business and Finance, Sun Yat-sen University, Guangzhou, China
\textsuperscript{b}School of Finance, Shandong University of Finance and Economics, Jinan, China
\textsuperscript{c}Department of Applied Finance, Macquarie University, Sydney, NSW, Australia
\textsuperscript{d}Department of Finance, School of Economics and Management, Wuhan University, Wuhan, China

Abstract

The COVID-19 pandemic is significantly disrupting human capital in labour markets. Workforce reductions cause firm outputs to fall and prices to rise, leading to unprecedented economic costs. To quantify the economic costs, we develop a dynamic general equilibrium macroeconomic model that incorporates susceptible–infectious–recovered epidemiology dynamics, where individuals can be healthy, infected or recovered so that evolution of human capital can be well tracked. We characterise optimal public policy responses to the decline in human capital by either isolating susceptible residents from infected residents to reduce the spread of disease or increases in government spending to improve the recovery and death rates.

Key words: COVID-19; Human capital; Public policy; Economic policy; Economic benefit

JEL classification: I18, E63, E32

doi: 10.1111/acfi.12770

1. Introduction

The COVID-19 pandemic is having an unprecedented disruptive effect on human capital in labour markets, leading to significant economic costs (e.g., decline in firm output, output price increases, etc.). The pandemic is impacting the availability of workforces world-wide through three channels: morbidity due to infection, morbidity arising from caregiving for others, and mortality due to infection (McKibbin and Fernando, 2020). In addition, governments are...
trying to stop the spread of the virus by severely restricting travel and in-person commercial activities, which influences the workforce participation rate (Guan et al., 2020). Thus, understanding the impact on workforce reductions of the spread of COVID-19 as well as the governmental responses is critical to understanding the macroeconomic impact of the pandemic.

This paper proposes a novel framework to examine the joint determination of the transmission of COVID-19, human capital and macroeconomic equilibrium in a dynamic general equilibrium model. The modelling of COVID-19 transmission based on susceptible–infected–recovered (SIR) dynamics enables us to isolate the effect of COVID-19 that is associated with human capital on the macroeconomic environment. We also characterise the appropriate government policy responses to the decline in healthy human capital. Using data from China, we quantify the economic benefits of these policy responses.

To model the interaction between COVID-19, human capital and the macroeconomic environment, we extend the dynamic general equilibrium model of Eichenbaum et al. (2020b). In our model, the contact frequency is decreasing with the level of lockdown, and the mortality rate and recovery rate are related to accumulated healthy capital. Households gain utility from consumption and leisure of different family members, and lockdown can reduce households’ income and increase their consumption costs. In addition, there are two types of firms: final goods producers and intermediate goods producers. The authors suggest that the government influences the transmission of the epidemic and macroeconomic environment through lockdown and fiscal expenditure. As the COVID-19 pandemic reduces the number of people who are able to work, the output of some firms and the income of households will decline, which would lead to a further decline in consumption and investment. After developing our SIR model, where individuals are either healthy or infected by COVID-19, and disease transmission is determined by the contact frequency, recovery and death rates, we integrate the dynamics of COVID-19 transmission into an economic model to capture the economic impacts. The government can implement public policies to improve the human response to COVID-19 by either isolating susceptible residents from infected residents, which reduces human interactions and the number of infected individuals, or increasing government expenditures on public health initiatives to improve the recovery rate and reduce the death rates. We study the model’s dynamic equilibrium and characterise the optimal government public policy responses by obtaining the optimal values for the lockdown and healthcare expenditures.

We find:

1 In the short run, the outbreak of COVID-19 leads to a decline in labour forces and firm outputs. In the long run, the highly infectivity of COVID-19 can change the economic steady state (long-run equilibrium) through the reduction of healthy human capital and labour participation rate.
2 The lockdown policy would prolong the duration of the epidemic by about 7 weeks and decrease the number of deaths by 14.82 percent.
3 The fiscal policy of increasing health investment expenditure can reduce the number of deaths by 11.59 percent without prolonging the duration of the epidemic, and then, reduce the decrease in consumption and output by 10.94 and 7.75 percent, respectively.
4 Overall, the combination of the two policies can reduce the number of deaths by 3.97 percent compared to lockdown and by 7.2 percent compared to fiscal expenditure. The consumption and output losses would be reduced by 9.75 percent and 9.04 percent, compared to the lockdown policy, and 6.57 and 4.54 percent, compared to the fiscal policy.

We contribute to the literature by providing a novel theoretical model and empirical findings regarding the impact of a sudden health shock on the macroeconomic environment. Previous studies highlight the impact of infectious disease on the economy, but they mainly focus on the long-term impact of periodic infectious diseases. For example, Goenka and Liu integrate the SIS model and assess the economic impact of infectious disease. Fogli and Veldkamp (2012) investigate the role of network connectivity in the diffusion of knowledge and diseases and how they affect economic growth, while Goenka et al. (2014) observe that spending on public health affects the probability of being infected and resultant recovery times. More recently, Goenka and Liu analyse the impact of infectious diseases on human capital accumulation and poverty levels. Differing from these studies, we focus on the sudden outbreak of a pandemic and its economic impact.

We also contribute to the literature that studies the impact of the COVID-19 pandemic. Baker et al. (2020) empirically analyse the unprecedented impact of COVID-19 on stock market volatility and argue that government restrictions on commercial activity and voluntary social distancing have a huge impact on service-oriented economies, resulting in the violent volatility of the US stock market. Chen et al. (2020) use daily transaction data in 214 cities in China to study the impact of COVID-19 on consumption and find that daily offline consumption fell by 32 percent, or 18.57 million RMB per city, during a 12-week period. Besides empirical study, Faria-e-Castro (2020) builds a dynamic stochastic general equilibrium model with two types of households (saver and borrower) and two types of firms (service firm and non-service firm) to study the deep recession triggered by the pandemic shock and the effectiveness of different types of fiscal policies. Guerrieri et al. (2020) build a two-sector general equilibrium model to study the mechanism of how a supply shock causes demand shortage. Further research introduces epidemiology into the economic model to describe the dynamics of COVID-19 and the possible impact on the economy, such as Eichenbaum et al. (2020b), who find that the optimal containment policy increases the severity of the recession but saves roughly 0.6 million lives in the US. Alvarez et al. (2020) utilise the SIR
epidemiology model and a linear economy to analyse the optimal lockdown policy, and find that the optimal policy prescribes a severe lockdown beginning two weeks after the outbreak, covering 60 percent of the population after a month.

In addition, our current study has some limitations. We ignore the probability that infected residents would produce antibodies and become immune to COVID-19. Furthermore, we do not consider the case that the government can develop a vaccine or other immunotherapeutic strategies to fight the COVID-19 pandemic. If those cases are considered, the impact of the COVID-19 pandemic on the economy may decline, including the magnitude and length.

2. The model

2.1. Households

In the model, we assume that the households \( (N_t) \) can be divided into three categories: susceptible individuals \( (S_t) \), infected individuals \( (I_t) \) and recovered individuals \( (R_t) \), that is \( N_t = S_t + I_t + R_t \). Infected individuals lose their ability to work while sick and can spread the disease, while susceptible and recovered work-age individuals can still potentially participate in the workforce. The infected individuals will recover, continue to receive treatment, or die. Let \( \alpha_t \) denote the probability of a susceptible individual coming into contact with an infected individual in a unit of time, referred to as the contact frequency; \( \mu_{rt} \) denote the probability of an infected individual recovering in a unit of time, referred to as the recovery rate; and \( \mu_{dt} \) denote the probability of a death in a unit of time, referred to as the death rate. In each period, the number of newly infected individuals is thus denoted as \( \alpha_t I_t S_t \), the number of recovered individuals is denoted as \( \mu_{rt} I_t \) and the number of deaths of infected individuals is \( \mu_{dt} I_t \). Individuals who recover typically became healthy over time and become immune to the disease. Thus, the population of the three household categories is adjusted according to the SIR dynamic system (Kermack and McKendrick, 1927; Eichenbaum et al., 2020a, 2020b), determined as follows:

\[
\text{Susceptible individuals: } S_{t+1} = S_t - \alpha_t I_t S_t. \tag{1}
\]

\[
\text{Infected individuals: } I_{t+1} = (1 - \mu_{rt} - \mu_{dt}) I_t + \alpha_t I_t S_t. \tag{2}
\]

\[
\text{Accumulated Recovered individuals: } R_{t+1} = R_t + \mu_{rt} I_t. \tag{3}
\]

\[
\text{Accumulated Dead individuals: } D_{t+1} = D_t + \mu_{dt} I_t. \tag{4}
\]

Different from Eichenbaum et al. (2020b), in our paper, parameters \( \{\alpha_t, \mu_{rt}, \mu_{dt}\} \) are all endogenous and related with the public policies of governments.
Contact frequency, $\alpha_t$, is determined by the degree of lockdown (Alvarez et al., 2020; Stock, 2020); therefore, we assume that $\alpha_t$ changes according to the following equation:

$$\alpha_t = \theta (1 - \nu \omega_t)^2$$  \hspace{1cm} (5)

where $\omega_t \in [0, 1]$ denotes the degree of lockdown, and $\nu \leq 1$ denotes the effectiveness of lockdown. Following studies such as Goenka et al. (2014), $\mu_{rt}$ and $\mu_{dt}$ are both endogenous and determined by the amount of healthy capital accumulation, $H_t$, i.e., $\mu_{rt} = r(H_t)$ and $\mu_{dt} = d(I_t, H_t)$, and the functions $r(\cdot)$ and $d(\cdot)$ satisfy the following assumption:

$$\begin{align*}
\frac{\partial \mu_{rt}}{\partial H_t} &\geq 0, \quad \frac{\partial^2 \mu_{rt}}{\partial H_t^2} \leq 0, \lim_{H_t \to 0} \frac{\partial \mu_{rt}}{\partial H_t} < \infty, \lim_{H_t \to \infty} \frac{\partial \mu_{rt}}{\partial H_t} = 0; \\
\frac{\partial \mu_{dt}}{\partial H_t} &\leq 0, \quad \frac{\partial^2 \mu_{dt}}{\partial H_t^2} \geq 0, \lim_{H_t \to 0} \frac{\partial \mu_{dt}}{\partial H_t} > -\infty, \lim_{H_t \to \infty} \frac{\partial \mu_{dt}}{\partial H_t} = 0.
\end{align*}$$  \hspace{1cm} (1, 2)

The accumulation of healthy capital is given by

$$H_{t+1} = (1 - \delta_h)H_t + I_{H_t}$$  \hspace{1cm} (6)

where $\delta_h$ denotes the depreciate rate of healthy capital, and $I_{H_t}$ denotes investment of healthy capital by governments.

Assuming that each period the labour market real wages are $W_t$ and the working hours are $L_{Mt}$, $M \in \{S, I, R\}$, and then obtain income $W_t \sum L_{Mt}$. $R^k_t$ denotes the capital return, where $R^k_t$ denotes the gross rate of return on capital and $K_t$ denotes the accumulated physical capital as given by:

$$K_{t+1} = (1 - \delta_k)K_t + I_{K_t},$$  \hspace{1cm} (7)

where $\delta_k$ denotes the capital depreciation rate and $I_{K_t}$ denotes investment. A household would obtain profit $J_t$ by owning part of a firm, pay the net lump-sum tax $T_t$ to the government, and then consume, purchase bonds and invest using the disposable income. Therefore, the household’s budget constraint is given by:

$$\sum_{M \in \{S, I, R\}} M_t \left[ \frac{C^i_{M_t}}{(1 - \nu \omega_t)^2} - (1 - \nu \omega_t)^2 W_t L^i_{Mt} \right] + \tilde{H}^i_{K_t} \leq (R^k_t - 1)K^i_t + J^i_t - T^i_t.$$  \hspace{1cm} (8)

Given that the utility of a representative household depends on consumption, leisure and the household members’ health:
$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \sum_{M \in \{S,I,R\}} M_i \left[ \frac{(C_{Mt})^{1+\sigma}}{1+\sigma} - \frac{\chi_L(L_{Mt})^{1+\phi}}{1+\phi} \right] \right\} + \chi_N N_i \right\} \right\}, \tag{9}$

where $\chi_L$ is the share of labour in the utility and $\chi_N$ is the share of life in the utility.

A representative household maximises utility function (9) subject to Equations (7) and (8) yielding

$$\chi_L(L_{Mt})^{\alpha} (C_{Mt})^{\alpha} = (1 - \nu a_t)^4 W_t, \tag{10}$$

$$(1 - \nu a_t)^2 (C_{Mt})^{-\sigma} = \beta(1 - \nu a_{t+1})^2 (C_{Mt+1})^{-\sigma} (R_{t+1}^k - \delta_k). \tag{11}$$

### 2.2. Firms

Next, we consider two types of firms: final goods producers and intermediate goods producers. The final goods producer purchases intermediate goods $Y_{jt}$ from the intermediate goods producer at price $P_{jt}$, and produces final goods $Y_t$ according to constant elasticity of substitution (CES) technology:

$$Y_t = \left[ \int_0^1 \left( Y_{jt} \right)^{\frac{\varepsilon - 1}{\varepsilon}} dj \right]^{\frac{1}{1-\varepsilon}}. \tag{12}$$

The final goods market is competitive. Given the intermediate goods price $P_{jt}$, the final goods producer minimises the cost $\int_0^1 P_{jt} Y_{jt} dj$ subject to the constraint of Equation (12). Then the demand function of intermediate goods $j$ is obtained as follows:

$$Y_{jt} = \left( \frac{P_{jt}}{P_t} \right)^{-\varepsilon} Y_t, \tag{13}$$

where $P_t = \left[ \int_0^1 \left( P_{jt} \right)^{1-\varepsilon} dj \right]^{\frac{1}{1-\varepsilon}}$ denotes the consumption price index. Intermediate goods producers are typically monopolistic competitors and use capital and labour as distinguishing factors to produce goods. Their production is given by:

$$Y_{jt} = A(K_{jt})^\mu (L_{jt})^{1-\mu}, \tag{14}$$

where $Y_{jt}$ denotes the output of intermediate goods, and $K_{jt}$ and $L_{jt}$ denote the capital and labour used in the production of these goods, respectively. $A$ denotes the total factor productivity across all common goods producers,
which can be calibrated to pin down the output. The intermediate goods producer maximises profit 
\[ P_j^t = \frac{\varepsilon}{\varepsilon - 1} MC_j P_t, \]  
where

\[ MC_j = \frac{W_t^\mu (R_j^k - 1)^{1-\mu}}{A \mu^\mu (1-\mu)^{1-\mu}} \]  

denotes the real marginal cost faced by the intermediate goods producer, and the demand of capital and labour:

\[ \frac{R_j^k - 1}{W_t} = \frac{\mu}{1 - \mu} \frac{L_j}{K_j^{l-1}}. \]  

2.3. Government

We assume that government’s actions impact the economy through various public and fiscal policies. First, during a disease outbreak, a government may require individuals to isolate themselves to reduce their exposure to the disease, which is captured by lockdown rate \( \omega_t \) in Equations (5) and (8). Second, the government may increase public health expenditures through fiscal policies to facilitate disease mitigation, which is captured by healthy investment \( I_{H_t} \) in Equation (6). Based on these government policies, the recovery and death rates from the disease now are defined by:

\[ \mu_{rt} = \gamma_1 - \gamma_2 e^{-\gamma_3 H_t}, \]  
\[ \mu_{dt} = \kappa P_t^2 + d_1 + d_2 e^{-d_3 H_t}. \]  

where \( \kappa \) denotes the increase in mortality rate as the increase in number of infected individuals, as in Eichenbaum et al. (2020a) and Alvarez et al. (2020). We will show that it is an important channel for lockdown to work well.

2.4. Equilibrium

The goods produced by a final goods producer are used for household consumption, physical investment, healthy capital investment and government consumption, that is: 
\[ Y_t = C_t + I_{Kt} + I_{Ht} + G. \] At equilibrium, all goods are sold
at the same price, which means that $P^t_i = P_t$, then we have: $Y^t_i = Y_t$ and $MC_t = (\varepsilon - 1)/\varepsilon$. The aggregated consumption and labour are given by:

$$L_t = S_tL_{St} + I_tL_{It} + R_tL_{Rt}$$  \hspace{1cm} (20) \\
$$C_t = S_tC_{St} + I_tC_{It} + R_tC_{Rt}$$  \hspace{1cm} (21)

3. The economic impact of the COVID-19 pandemic

In this section, we calibrate the model using COVID-19 data for China to examine the impact of the pandemic on the macroeconomy.

3.1. Model calibration

The model involves 19 parameters: eight conventional parameters $\{\beta, \sigma, \chi_L, \varphi, \varepsilon, \delta_k, \mu, A\}$ and 11 specific parameters $\{\chi_N, v, \delta_h, \theta, \kappa, \gamma_1, \gamma_2, \gamma_3, d_1, d_2, d_3\}$. We begin with the conventional parameters: we set the discount factor $\beta$ to 0.9641/52, which means that the average risk-free nominal interest rate at the steady state is 3.76 percent (annualised); we set $\sigma$ to 2. As in Eichenbaum et al. (2020b), we set the Frisch elasticity of labour $\varphi$ to 1 and set the elasticity of substitute between goods $\varepsilon$ to 3.86 which means the markup is 35 percent; for the depreciation rate of physical capital $\delta_k$, we follow many studies (e.g., Gertler and Karadi, 2011) to set it as $\delta_k = 1.1^{1/52} - 1$; for the share of capital in common goods production, we set $\mu$ to 0.4 based on the actual situation in China. We calibrate $\chi_L$ to pin down $L_{ss} = 40$ at steady state, and calibrate $A$ to pin down $Y_{ss} = 30733/52$ at steady state.

For the 11 specific parameters, the effectiveness of lockdown is set to $v = 0.5$ as in Alvarez et al. (2020), the depreciation rate of healthy individuals is set to $\delta_h = 70$ percent for most medical equipment cannot be reused. We set $\theta$ to 2.5 and $\kappa$ to 1.2. At the end of May 2020, the number of confirmed COVID-19 cases in China was lower than 100 for more than two weeks, the death was zero for more than one and a half months, and except for imported cases, the number of confirmed new cases was nearly zero for more than one month. The data imply that the then-current wave of COVID-19 in China was almost over, and we can use the data to calibrate the death rate from COVID-19. According to data published by National Health Commissions of the People’s Republic of China, between 26 January 2020 and 12 April 2020, the mortality rate fluctuated between 0.87 and 2.83 percent, while the recovered rate fluctuated between 0.80 and 100.69 percent. The average mortality rate was 1.48 percent and the recovered rate was 53.33 percent. Therefore, we calibrate $\{d_1, d_2, d_3\}$ to pin down $\mu_{dss} = 1.48$ percent at a high level of healthy capital; we calibrate $\{\gamma_1, \gamma_2, \gamma_3\}$ to pin down $\mu_{rss} = 53.33$ percent at a high level of healthy capital.

Table 1 lists the parameter values we choose when calibrating the model.
Concerning the policies, the low level of healthy capital is set to $H_{\text{low}} = 24.78$ and the high level of healthy capital is set to $H_{\text{high}} = 34.7$. The lockdown level when there is only lockdown policy is set to $\omega = 40$ percent, while the lockdown level is set to $\omega = 20$ percent when the two policies are combined. The weeks of fiscal expenditure and lockdown are the eighth to twenty-fourth week.

### Empirical results

The case of no lockdown ($\omega = 0$) and low level of health expenditure ($H = H_{\text{low}}$) can be considered as a benchmark scenario. Figure 1 shows that after the shock of the COVID-19 pandemic hits the economy, it needs 16 weeks for the current confirmed cases to reach the turning point, at which time 59.76 percent of the population is confirmed to be infected. After 16 weeks, the ratio of accumulated recovered residents and accumulated dead residents begins to rise rapidly, and after 27 weeks, the ratio of accumulated recovered residents remains stable at 56.93 percent while the ratio of accumulated deaths remains stable at 44.72 percent.
In addition, after the outbreak of COVID-19, the labour supply declines by about 12.5 percent, while consumption increases by about 9.8 percent for the high wage group. As the number of infected residents increases gradually, the labour supply declines further and consumption decreases gradually. At the beginning of COVID-19, capital return increases more than wages and then investment decreases more than labour. After the turning point, the large number of dead residents leads to very high wage and relatively low capital return, then investment increases immediately from $-53.75$ to $-6.64$ percent. The decline in labour supply and investment leads to a decline in output which decreases by 7.70 percent at the beginning of COVID-19 and then drops by 28.23 percent after the turning point. The labour supply and consumption drop immediately by 48.85 and 38.81 percent, respectively, because a large number of people die and lots of people cannot work after being infected.

Figure 1  Response to the COVID-19 shock without public policies.

Notes: The green dashed line denotes zero level; the solid line denotes the response of variables. Labour, Consumption, Output, Investment and Wage denote percentage deviation from steady state; Capital return (annualised), Infected, Population and Death denote level value. We assume that the population is unity before the COVID-19 pandemic hits the economy. There are no public policies: $\omega = 0$ and $H_t = H_{low}$.
4. The economic effect of public policies

4.1. The effect of lockdown

The first type of government response to the affected human capital is to isolate susceptible residents from infected residents. Panel A of Figure 2 shows the impact on the economy of lockdown policy.

The lockdown policy has two important impacts on epidemics. Firstly, it would decrease the number of infected and dead residents. Secondly, it would prolong the duration of the epidemic. After implementing the lockdown, the number of deaths at last decreases from 44.72 to 29.90 percent, and the healthy

![Figure 2](image_url)  
**Figure 2** Response to the COVID-19 shock with lockdown.  
*Notes:* The black solid line denotes response of variables without public policies; the red solid line denotes response of variables under lockdown policy. Labour, Consumption, Output, Investment and Wage denote percentage deviation from steady state; Capital return (annualised), Infected, Population and Death denote level value. We assume that the population is unity before the COVID-19 pandemic hits the economy. Under lockdown policy, \( \omega = 40\% \) and \( H_t = H_{\text{low}} \).
population increases from 55.28 to 70.10 percent. The epidemic lasts for 27 weeks without lockdown and it needs 34 weeks with lockdown. Fewer deaths leads to less decline in consumption and labour supply, and then less decline in output and investment. The lockdown reduces the loss of consumption by 13.88 percent and reduces the loss of output by 9.72 percent. However, the gain from lockdown is related to the parameter $\kappa$, which reflects the capacity to treat patients. A high level of $\kappa$ means lower capacity and as the number of infected residents increases, the mortality rate increases more rapidly. Panel B of Figure 2 shows that when $\kappa$ becomes zero, lockdown just prolongs the duration of the epidemic and does not bring any economic gain.

4.2. The effect of healthy capital investment

The second type of government response to the affected human capital is to increase fiscal expenditure to build more healthy capital. Figure 3 shows the influence of healthy expenditure on the economy. Different from lockdown, healthy expenditure would only decrease the number of deaths and would not influence the duration of the epidemic.

A high level of fiscal expenditure can reduce the death rate and increase the recovery rate. A higher recovery rate would decrease the number of currently infected residents and then decrease the death rate further if $\kappa > 0$. Fiscal expenditure leads to 11.59 percent fewer deaths after the end of the epidemic. As a result, more people are surviving, leading to a greater labour supply and more consumption. Because of the high level of fiscal expenditure, the labour supply decreases by 31.12 percent, which is 10.70 percent less than with a low level of fiscal expenditure; consumption decreases by 29.22 percent, which is
10.94 percent less than with a low level of fiscal expenditure. Higher labour supply leads to higher output, and a high level of fiscal expenditure leads to 7.75 percent less loss of output.

### 4.3. The effect of policy combination

Lockdown can decrease the number of infected and dead residents, but would prolong the duration of the epidemic, while excessive fiscal expenditure would increase the government’s financial burden. Then it is necessary to implement the two policies in combination. Figure 4 illustrates the difference in impact between implementing the two policies separately and in combination. On the one hand, when the two policies are implemented in combination, the number of deaths declines to 25.94 percent, which is 3.97 percent less than with lockdown and 7.20 percent less than with fiscal expenditure. On the other hand, when the two policies are implemented in combination, the epidemic lasts for 27 weeks, which is the same as with the benchmark (no policy) and 7 weeks less than with lockdown.

Regardless of whether the intervention takes places during the epidemic or after the end of the epidemic, combination of the two policies can take advantage of their benefits. Taking labour, for example, at the eighth week, labour declines by 13.28 percent and then remains fixed for 10 weeks with policy combination, while labour declines by 24.94 percent with lockdown and...
then remains fixed at the low level of labour for 10 weeks. After the end of the epidemic, under policy combination, the labour supply declines by 24.46 percent which is 3.69 percent less than with lockdown policy and 6.66 percent less than with fiscal expenditure policy. As for output, during the epidemic, after the fiscal expenditure works (eighth week to sixteenth weeks), output declines 9.04 percent less than with lockdown, and consumption declines 9.75 percent less than with lockdown. After the end of the epidemic, output declines 15.95 percent, which is 2.57 percent less than with lockdown and 4.54 percent less than with fiscal expenditure, and consumption declines 22.64 percent, which is 3.62 percent less than with lockdown and 6.57 percent less than with fiscal expenditure.

5. The difference between the COVID-19 and other infectious disease outbreaks

In this paper, we discuss the economic effect of two policies: lockdown and healthy capital expenditure. Lockdown aims at the contact rate $\alpha_t$ through the equation

$$\alpha_t = \theta(1 - \nu_0 t)^2,$$

while healthy capital expenditure aims at the recovery rate $\mu_{rt}$ and mortality rate $\mu_{dt}$ through the equations

$$\mu_{rt} = \gamma_1 - \gamma_2 e^{-\gamma_3 H_t},$$

$$\mu_{dt} = \kappa I_t^2 + d_1 + d_2 e^{-d_3 H_t}.$$ As for healthy capital expenditure policy, the effect of the policy on recovery rate and mortality are similar to previous infectious diseases like the 1918–19 Spanish flu. These functions are convenient to describe the effect of healthy capital expenditure on the recovery rate and mortality rate.

Parameters $\{\gamma_1, \kappa, d_1\}$ reflect the characteristic of disease itself and are not related to policy. Parameters $\{\gamma_2, \gamma_3\}$ and $\{d_2, d_3\}$ are related to healthy capital expenditure policy and decide the effects of the policy through the channel of recovery rate and mortality rate respectively. According to the equation,

$$\mu_{dt} = \gamma_1 - \gamma_2 e^{-\gamma_3 H_t},$$

we have $\frac{\partial \mu_{dt}}{\partial H_t} = \gamma_2 \gamma_3 e^{-\gamma_3 H_t} > 0$, $\frac{\partial^2 \mu_{dt}}{\partial H_t^2} = -\gamma_2 \gamma_3^2 e^{-\gamma_3 H_t} < 0$ and $\frac{\partial^2 \mu_{dt}}{\partial H_t \partial \gamma_2} = -\gamma_2 \gamma_3 e^{-\gamma_3 H_t} < 0$. The expressions mean that higher values of $\gamma_2$ and lower values of $\gamma_3$ can lead to a higher recovery rate when increasing healthy capital expenditure. Similarly, according to the equations,

$$\mu_{dt} = \kappa I_t^2 + d_1 + d_2 e^{-d_3 H_t},$$

we have $\frac{\partial \mu_{dt}}{\partial H_t} = -d_2 d_3 e^{-d_3 H_t} < 0$, $\frac{\partial^2 \mu_{dt}}{\partial H_t \partial d_3} = -d_3 e^{-d_3 H_t} < 0$ and $\frac{\partial^2 \mu_{dt}}{\partial H_t \partial d_2} = -d_2 (1 - d_3 H_t) e^{-d_3 H_t} > 0$. The expressions mean that higher values of $d_2$ and lower values of $d_3$ can lead to lower mortality rate when increasing healthy capital expenditure.

From Panels A and B of Figure 5, we know that when parameter $\gamma_2$ increases from 2 to 2.5 or parameter $\gamma_3$ decreases from 0.1 to 0.08, increasing healthy capital expenditure can lead to higher increase in recovery rate, higher decrease in number of deaths and then higher increase in consumption, output, labour and investment. From Panels C and D of Figure 5, we know that when parameter $d_2$ increases from 0.6 to 0.9 or parameter $d_3$ decreases from 0.1 to 0.08, increasing healthy capital expenditure can lead to higher decrease in death rate, but does not lead to higher increase in consumption, output, labour and investment.

© 2021 Accounting and Finance Association of Australia and New Zealand
Figure 5  The impact of healthy capital expenditure policy parameters on economy.

Notes: The red solid line denotes the difference in impulse response of variables between high expenditure and low expenditure at benchmark model; the black dashed line denotes the difference in impulse response of variables between high expenditure and low expenditure at new policy parameters. Labour, Consumption, Output and Investment denote percentage deviation from steady state; Infected, Death, Death rate and Recovery rate denote level value.
As discussed in Baker et al. (2020), the lockdown policy is the most important government policy implemented during the COVID-19 pandemic compared with previous outbreaks of infectious diseases. The lockdown policy has an important impact on the service industries. In this paper, parameter $\nu$ reflects the effectiveness of the lockdown policy. It describes the degree to which industries are impacted, and thus, the larger the value of $\nu$, the more serious the industries are impacted. To begin with, we calibrated $\nu = 0.5$ as it was in Alvarez et al. (2020). Here, we change the value of $\nu$ to 0.6 to test the sensitivity to the lockdown policy. We find from Figure 6 that a higher value of $\nu$ leads to a larger decrease in labour, consumption and output at the beginning of lockdown. This is because more industries are affected, and more residents are unable to work.

6. Conclusion

We integrate the SIR model into the dynamic general equilibrium macroeconomic model to analyse the combination of fiscal expenditure and lockdown after the COVID-19 pandemic hits the economy. We also characterise the optimal public policies in response to the reduction in human capital by either

© 2021 Accounting and Finance Association of Australia and New Zealand
isolating susceptible residents from infected residents to decrease disease transmission or increasing the expenditures on public health initiatives to facilitate the recovery rate and decrease the mortality rate. We quantify the economic benefits of these policy responses.

Our results show that the reduction in human capital due to the outbreak of COVID-19 generates large economic costs, with resultant falls in consumption and outputs. The lockdown would prolong the duration for about 7 weeks and decrease the number of deaths by 14.82 percent. However, the effect of lockdown depends on the capacity to treat patients. If the capacity is large enough, the lockdown just prolongs the duration and cannot decrease the number of deaths. Fiscal expenditure can reduce the number of deaths by 11.59 percent without prolonging the duration, together with a lower decrease in consumption and output of 10.94 and 7.75 percent, respectively. However, excessive fiscal expenditure would increase the government’s financial burden. Combination of the two policies can reduce deaths by 3.97 percent relative to lockdown policy and by 7.2 percent relative to fiscal expenditure policy without prolonging duration. Then consumption and output loss would reduce by 9.75 and 9.04 percent, respectively, relative to lockdown policy during the epidemic.

References

Alvarez, F. E., D. Argente, and F. Lippi, 2020, A simple planning problem for COVID-19 lockdown, NBER Working Paper No. 26981.

Baker, S. R., N. Bloom, S. J. Davis, K. J. Kost, M. C. Sammon, and T. Viratyosin, 2020, The unprecedented stock market impact of COVID-19, NBER Working Paper No. 26945.

Chen, H., W. Qian, and Q. Wen, 2020, The impact of the COVID-19 pandemic on consumption: learning from high frequency transaction data. Available at: http://dx.doi.org/10.2139/ssrn.3568574.

Eichenbaum, M. S., S. Rebelo, and M. Trabandt, 2020a, The macroeconomics of epidemics, NBER Working Paper No. 26882.

Eichenbaum, M. S., S. Rebelo, and M. Trabandt, 2020b, Epidemics in the neoclassical and new Keynesian models, NBER Working Paper No. 27430.

Faria-e-Castro, M., 2020, Fiscal policy during a pandemic. Federal Reserve Bank of St. Louis Working Paper No. 2020–006.

Fogli, A., and L. Veldkamp, 2012, Germs, social networks and growth, NBER Working Paper No. 18470.

Gertler, M., and P. Karadi, 2011, A model of unconventional monetary policy, *Journal of Monetary Economics* 58, 17–34.

Goenka, A., L. Liu, and M. H. Nguyen, 2014, Infectious diseases and economic growth, *Journal of Mathematical Economics* 50, 34–53.

Guan, D., D. Wang, S. Hallegatte, et al., 2020, Global supply-chain effects of COVID-19 control measures, *Nature Human Behaviour* 4, 577–587.

Guerrieri, V., G. Lorenzoni, L. Straub, and I. Werning, 2020, Macroeconomic implications of COVID-19: can negative supply shocks cause demand shortages?, NBER Working Paper No. 26918.
Kermack, W. O., and A. G. McKendrick, 1927, A contribution to the mathematical theory of epidemics, *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* 115, 700–721.

McKibbin, W., and R. Fernando, 2020, The global macroeconomic impacts of COVID-19: seven scenarios, CAMA Working Paper 19/2020.

Stock, J. H., 2020, Data Gaps and the Policy Response to the Novel Coronavirus, National Bureau of Economic Research, Working Paper, No. 26902. https://doi.org/10.3386/w26902