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The Macroeconomic Impact of Labor Force Loss Due to Long COVID

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Abstract This paper examines how labor force losses caused by taking leave or resigning due to long COVID affect the macroeconomy. The analysis yielded the following results. First, a simulation analysis was conducted using a model that does not take unemployment into account. It was found that a 3% loss in the labor force leads to a 2% decrease in Gross Domestic Product (GDP). Furthermore, even when the degree of labor force loss is reduced, it takes a longer time for GDP to return to its original level. Similarly, when frictional unemployment is taken into account, it was found that even after the labor force recovers, it still takes a longer time for GDP to return to its pre-loss level.

Keywords：Long COVID、Labor force losses、Ramsey model
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† Any remaining errors are solely the responsibility of the author.

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1. Introduction

Since 2020, the spread of COVID-19 has become a major issue, significantly restricting economic activity—particularly in the restaurant and tourism industries. As a result of declining private demand, gross domestic product (GDP) experienced a substantial downturn.[1] According to data from the Ministry of Internal Affairs and Communications, consumption in the second quarter of 2020 declined by 10% compared to the end of 2019, indicating that economic activity was significantly constrained.[2] In addition, data from the Cabinet Office shows that expenditures on services in April 2020 dropped by approximately 35% compared to the average from 2016 to 2018.[3]

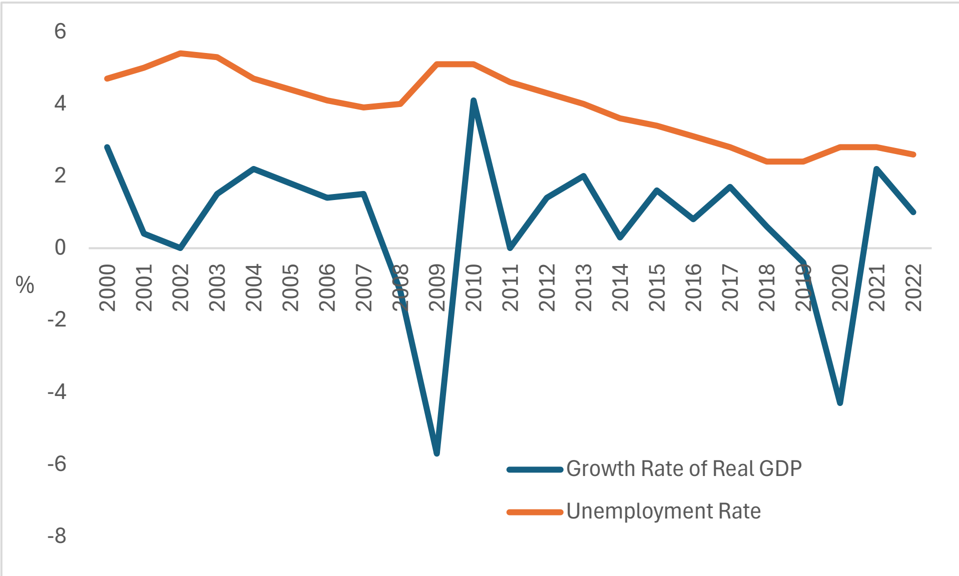

Fig. 1 ：Real GDP and Unemployment Rate（Data：Cabinet Office, Government of Japan (2023), "Economic and Fiscal White Paper: Long-Term Economic Statistics, FY2023", Japan Institute for Labour Policy and Training (2024), "Quick Reference: Long-Term Economic Statistics in Graphs - Figure 1: Unemployment Rate and Job Openings-to-Applicants Ratio")

However, due to employment subsidies such as the Employment Adjustment Subsidy, the rise in the unemployment rate was somewhat contained, despite the suppression of economic

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[1] NHK "Situation During the First State of Emergency"

[2] Ministry of Internal Affairs and Communications (2021) "White Paper on Information and Communications, 2021 Edition"

[3] Cabinet Office, Government of Japan (2022), "Annual Economic and Fiscal Report, FY 2022"

activity caused by movement restrictions.[4] The macroeconomic effects of the Employment Adjustment Subsidy in mitigating unemployment have been analyzed using a DSGE (Dynamic Stochastic General Equilibrium) model by Yasuoka and Hasegawa (2024).
Recently, long COVID has emerged as a growing concern. Citing the WHO's definition, the Ministry of Health, Labour and Welfare of Japan describes long COVID as "a condition that occurs in individuals with a history of infection with SARS-CoV-2, with symptoms that last for at least two months and cannot be explained by an alternative diagnosis. These symptoms typically appear three months after the onset of COVID-19."

This so-called long COVID has also been discussed in NHK broadcasts. According to their reports, 6% of those infected with COVID-19 develop long COVID, and among those who sought treatment for long COVID at a particular hospital, 54.1% reported that their ability to work was affected. Based on these figures, it can be estimated that approximately 3.2% of the working population are in a condition that prevents them from working fully.

This paper explores the macroeconomic impact of labor force loss due to long COVID. The findings are as follows. First, a simulation using a model that does not account for unemployment shows that a 3% loss in labor force leads to a 2% decline in gross domestic product (GDP). Moreover, even when the degree of labor force loss decreases, it still takes a longer time for GDP to return to its original level. Similarly, when frictional unemployment is taken into account, the results remain consistent: even after labor force recovery, it takes longer for GDP to return to its pre-shock level.

The structure of this paper is as follows: Section 2 explains the setup of the model economy. Section 3 derives the equilibrium solution. Section 4 introduces frictional unemployment into the model and derives the corresponding equilibrium. Section 5 concludes the paper.

2. Model

2.1 Household

In this economic model, households are assumed to live infinitely and derive utility from consumption in each period. The utility function $u_t^{utility}$ is assumed as follows.

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[4] Japan Institute for Labour Policy and Training (2024), "Statistical Topics: Equilibrium Unemployment Rate and Demand-Deficient Unemployment Rate". For "Employment Adjustment Subsidy", Ministry of Health, Labour and Welfare, "Employment Adjustment Subsidy". Notably, during the COVID-19 pandemic, the Employment Adjustment Subsidy provided full support with a subsidy rate of 10/10, provided certain conditions were met. See Ministry of Health, Labour and Welfare "Employment Adjustment Subsidy (Special Measures in Response to the Impact of COVID-19)." See Ministry of Health, Labour and Welfare (2021), "Analysis of Labor Economy, 2021 Edition" about to what extent unemployment was actually mitigated.

$$u_t^{utility} = \sum_{s=t}^{\infty} \rho^{s-t} \frac{c_s^{1-\gamma}}{1-\gamma}, 0 < \rho < 1, \gamma < 1. \tag{1}$$

c_s denotes the consumption in s period. s and t denote the period.

Households are endowed with one unit of labor time, which they supply. However, to account for situations in which households are unable to work for various reasons, the amount of labor supplied is assumed to satisfy $l_t \leq 1$, with 1 as the reference level. Let w_t denote the wage rate.

Households also hold capital stock K_t, from which they earn interest income $r_t K_t$, where r_t is the interest rate. It is assumed that capital stock depreciates at a constant rate δ each period. The capital stock in the next period, K_{t+1}, is given by the following equation:

$$K_{t+1} = w_t l_t + r_t K_t + (1-\delta) K_t - c_t, 0 < \delta < 1. \tag{2}$$

By maximizing the utility function (1) subject to the capital accumulation equation (2) as a constraint, we obtain the following Euler equation for consumption:

$$c_{t+1} = \rho^{\frac{1}{\gamma}} (r_{t+1} + 1 - \delta)^{\frac{1}{\gamma}} c_t \tag{3}$$

2.2 Firm

Firms produce the final good Y_t by employing capital stock and labor as inputs. The production function is assumed to be of the Cobb-Douglas form, as shown below:

$$Y_t = A K_t^{\theta} l_t^{1-\theta}, 0 < A, 0 < \theta < 1. \tag{4}$$

Under the assumption of perfect competition, the wage rate and the interest rate can be expressed as follows:

$$w_t = (1-\theta) A \left(\frac{K_t}{l_t}\right)^{\theta} \tag{5}$$

$$r_t = \theta A \left(\frac{K_t}{l_t}\right)^{\theta-1} \tag{6}$$

This paper's economic model assumes the following form of wage rigidity:

$$w_t = \varepsilon (1-\theta) A \left(\frac{K_t}{l_t}\right)^{\theta} + (1-\varepsilon) w_{t-1}, 0 < \varepsilon < 1. \tag{7}$$

Here, when $\varepsilon = 1$, the wage in period t is determined solely by the marginal productivity of labor in that period, indicating a state of complete wage flexibility. As ε decreases, the wage level in period t becomes increasingly influenced by past wage levels, reflecting a higher degree of wage rigidity.

3. Equilibrium

This paper investigates how macroeconomic variables change in response to a decrease in labor supply using simulation analysis. To that end, a linear approximation is employed. The variable $\hat{x}_t$ denotes the percentage deviation of x_t from its steady-state value. Variables without the time subscript t represent their values in the steady state.

・Euler equation for consumption：Considering (3), we obtain the following equation.

$$\hat{c}_{t+1} = \frac{1}{\gamma}\frac{\hat{r}_{t+1}r}{r+1-\delta} + \hat{c}_t \tag{8}$$

・Capital accumulation：Considering (2), we obtain the following equation.

$$\widehat{K}_{t+1} = \frac{l}{K}w\widehat{w}_t + \frac{l}{K}w\hat{l}_t + r\hat{r}_t + (r+1-\delta)\widehat{K}_t - \frac{c}{K}\hat{c}_t \tag{9}$$

・GDP：Considering (4), we obtain the following equation.

$$\widehat{Y}_t = \theta\widehat{K}_t + (1-\theta)\hat{l}_t \tag{10}$$

・Wage rate：Considering (5), we obtain the following equation.

$$\widehat{w}_t = \theta\widehat{K}_t - \theta\hat{l}_t \tag{11}$$

・Interest rate：Considering (6), we obtain the following equation.

$$\hat{r}_t = (\theta-1)\widehat{K}_t + (1-\theta)\hat{l}_t \tag{12}$$

・Wage rigidity：Considering (7), we obtain the following equation.

$$\widehat{w}_t = \frac{\theta\varepsilon(1-\theta)A}{w}\left(K\widehat{K}_t - l\hat{l}_t\right) + (1-\varepsilon)\widehat{w}_{t-1} \tag{13}$$

The variables at the steady state are shown as follows.

$$r = \frac{1}{\rho} + \delta - 1 \tag{14}$$

$$w = (1-\theta)A\left(\frac{K}{l}\right)^{\theta} \tag{15}$$

$$\frac{K}{l} = \left(\frac{r}{\theta A}\right)^{\frac{1}{\theta-1}} \tag{16}$$

$$\frac{c}{K} = w\left(\frac{K}{l}\right)^{-1} + r - \delta \tag{17}$$

Given that the recent unemployment rate has been around 2%, the steady-state level of labor supply is set at $l = 0.98$.

The parameters are specified as follows:

γ	1.5
δ	0.05
θ	0.3

Table 1: Parameter Setting

These parameters are based on Eguchi (2011). The wage rigidity parameter ε and the technology parameter A are determined through calibration. The calibration is conducted as follows: based on the method shown in Eguchi (2011), the parameters are derived using the Markov Chain Monte Carlo (MCMC) method. The parameters estimated through this calibration process are the wage rigidity parameter ε and the productivity parameter A.

	Pre Distribution			Post Distribution		
	Mean	Distribution	Standard dev	Mean	Confidence interval	
ε	0.5	Normal	0.1	0.5017	0.3380	0.6678
A	1	Normal	0.1	0.9861	0.8202	1.1506

Table 2：Parameter settings

At this point, the shock is modeled as an employment shock. The prior distribution of the shock is assumed to follow an inverse gamma distribution with a mean of 0.1 and an infinite standard deviation. The data used for the calibration spans the period from 1994 to 2022.[5]

The data used for calibration includes GDP, consumption, real interest rate, real wage rate, and the rate of change in the unemployment rate. An HP filter is applied to these data series to extract the trend components, and the deviations from the actual values are calculated. These deviations are incorporated into the model as the deviation rates from the steady state. The five indicators are integrated into the calibration model in the following manner:

$$\hat{Y}_t^{obs} = \hat{Y}_t + u\hat{Y}_t \tag{A.1}$$

$$\hat{c}_t^{obs} = \hat{c}_t + u\hat{c}_t \tag{A.2}$$

$$\hat{r}_t^{obs} = \hat{r}_t + u\hat{r}_t \tag{A.3}$$

$$\hat{w}_t^{obs} = \hat{w}_t + u\hat{w}_t \tag{A.4}$$

$$\hat{u}_t^{obs} = \hat{u}_t + u\hat{u}_t \tag{A.5}$$

Let $\hat{x}_t^{obs}$ denote the deviation rate of variable x_t from its trend, and u $u\hat{x}_t$ represent the error term. The error terms $u\hat{Y}_t$, $u\hat{c}_t$, $u\hat{r}_t$, $u\hat{w}_t$, and $u\hat{u}_t$ are each assumed to follow a prior

[5] The data for GDP, consumption, real interest rate, and unemployment rate are taken from the Cabinet Office (2023), Annual Economic and Fiscal Report 2023: Long-Term Economic Statistics. The real interest rate is calculated by subtracting the inflation rate from the nominal interest rate (government bond yield). Data on real wages is sourced from the Monthly Labour Survey available via the e-Stat portal, the official website for Japanese government statistics.

distribution given by an inverse gamma function with an expected value of 0.1 and a standard deviation of infinity. Through the above calibration, the parameters shown in Table 2 are obtained.

The results derived under these parameters are as follows:

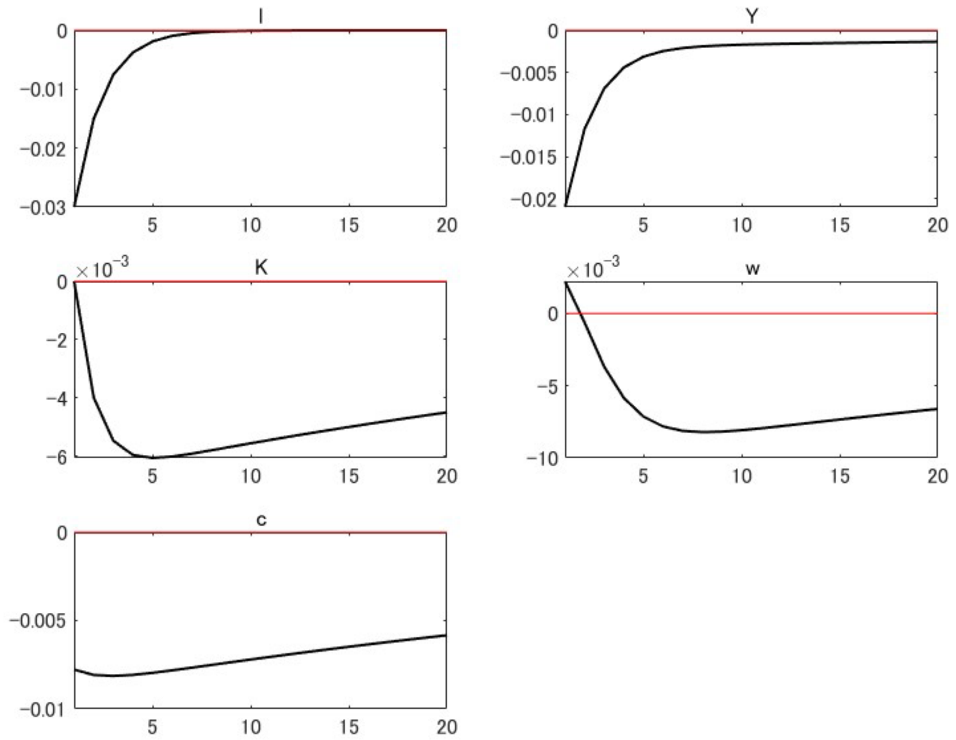

Fig.2：The Macroeconomic Impact of Labor Force Loss

4. The Case of Unemployment Model

In the previous section, the shock was described in terms of a reduction in labor supply. In this section, however, the shock is described in terms of the emergence of unemployment. This paper does not assume a full-employment model; rather, it is based on the assumption that imperfect information exists in the labor market, preventing complete matching between workers and firms. As a result, some job seekers may be unable to obtain their desired employment. This section explores a matching model of employment in such an imperfect labor market. For the purpose of this analysis, the study draws on Okada (2013) and adopts the matching model developed by Mortensen and Pissarides (1994).

There are various approaches to modeling the labor market. Okada (2013) assumes that the labor market is imperfect and that not all workers can be matched with employers, meaning that some remain unemployed. This assumption is also adopted by Eguchi and

Teramoto (2017). Both studies incorporate a labor market matching model into the DSGE framework to analyze the mechanism through which unemployment arises.

In contrast, Kato (2007) and Eguchi (2011) employ a standard DSGE model that does not account for unemployment, although labor supply is endogenized. Hayashida, Yasuoka, Nanba, and Ono (2018), building on the model developed by Ono (2010), incorporate unemployment by allowing labor unions to include both the income of employed workers and unemployment benefits for the unemployed in their objective function, thereby determining the wage and employment levels. Although such models of unemployment determination are relatively tractable, the conclusions drawn from the model economy may vary significantly depending on the unemployment model adopted.

Yasuoka and Hasegawa (2024) introduce a matching model that is relatively widely used in DSGE models to examine how demand shocks—such as those caused by behavioral restrictions during the COVID-19 pandemic—affected macroeconomic variables. In contrast, the present study analyzes the decline in labor supply using a Ramsey model.

4.1 Matching Model

We assume the following matching function.

$$M_t = BU_t^{\alpha}V_t^{1-\alpha}, 0 < B, 0 < \alpha < 1. \tag{18}$$

Let M_t denote the number of new hires, U_t the number of unemployed individuals, and V_t the number of job vacancies.

The probability of filling a vacancy, L_t, can be expressed as follows.

$$L_t = \frac{M_t}{V_t} = B\psi_t^{-\alpha}. \tag{19}$$

Here, $\psi_t = \frac{V_t}{U_t}$, which represents labor market tightness, or the job vacancy-to-unemployment ratio.

The probability of an unemployed individual finding a job, S_t, can be expressed as follows.

$$S_t = \frac{M_t}{U_t} = B\psi_t^{1-\alpha}. \tag{20}$$

The employment transition equation can be expressed as follows.

$$l_t = (1-\delta_n)l_{t-1} + V_t B\psi_t^{-\alpha}, 0 < \delta_n < 1. \tag{21}$$

It is assumed that a fraction δ_n of workers are separated from employment. The total number of employed individuals in period t consists of those who remain employed with probability $1-\delta_n$ and those newly hired.

4.2. Wage Determination

In a perfectly competitive market with complete information, the wage level coincides with the marginal productivity of labor. However, in this paper, the presence of informational imperfections prevents wages from being determined in the same way as in a perfectly competitive model. Instead, it is assumed that the wage level is determined through a Nash bargaining solution. Here, ξ is a parameter representing bargaining power, where a lower value of ξ implies stronger bargaining power for workers.

$$w_t = \text{argmax}(\theta_t^E - \theta_t^U)^{\xi}\left(\theta_t^J - \theta_t^V\right)^{1-\xi}, 0 < \xi < 1. \tag{22}$$

These variables are shown as follows.

$$\theta_t^E = w_t + E_t\left[\rho_{t+1}\left((1-\delta_n)\theta_{t+1}^E + \delta_n\theta_{t+1}^U\right)\right] \tag{23}$$

$$\theta_t^U = b_t^u + E_t\left[\rho_{t+1}\left((1-\delta_n)B\psi_t^{1-\alpha}\theta_{t+1}^E + (1-(1-\delta_n)B\psi_t^{1-\alpha})\theta_{t+1}^U\right)\right] \tag{24}$$

$$\theta_t^J = Y_t - w_t - r_tK_t + E_t\left[\rho_{t+1}(1-\delta_n)\theta_{t+1}^J\right] \tag{25}$$

$$\theta_t^V = -\frac{k\psi_t}{\lambda_t} + E_t\left[\rho_{t+1}\left((1-\delta_n)B\psi_t^{1-\alpha}\theta_{t+1}^J + (1-(1-\delta_n)B\psi_t^{1-\alpha})\theta_{t+1}^V\right)\right] \tag{26}$$

Here, $\rho_{t+1} = \rho\frac{\lambda_{t+1}}{\lambda_t}$ represents the discount factor evaluated by the household's marginal utility.[6] E_t denotes the expectation operator.

θ_t^E represents the value of a worker being employed and working in the current period. In the next period, there is a certain probability that the employment will continue and a certain probability that the worker will become unemployed, so the expected value of each outcome is taken into account.

On the other hand, θ_t^U represents the value of a worker being unemployed in the current period. In this case, the worker receives unemployment benefits b_t^u for the current period and, in the next period, has a certain probability of becoming employed and obtaining the value θ_{t+1}^E, or remaining unemployed and obtaining the value θ_{t+1}^U.

Next, we explain the value from the firm's perspective. θ_t^J represents the value of employing one worker. By hiring one worker, the firm earns a profit of $Y_t - w_t - r_tK_t$.
On the other hand, θ_t^V represents the value of not employing a worker. Here, k is the vacancy posting cost, and by taking into account the job vacancy rate, the cost per unemployed worker for posting a vacancy is derived. Furthermore, due to the free-entry condition for firms, it is assumed that $\theta_t^V = 0$.

The Nash bargaining solution given by equation (22) can be expressed as follows by solving

[6] Because of household maximization problem, we find that the marginal utility of consumption is given by $\lambda_t = c_t^{-\gamma}$.

for w_t.

$$(1-\xi)(w_t - b_t^u) - \frac{\xi \psi_t k}{\lambda_t} = \xi(Y_t - w_t - r_t K_t) \tag{27}$$

The probability of new employment can also be derived as shown in the following equation.

$$\frac{k}{\lambda_t \psi_t} = E_t\left[\rho \frac{\lambda_{t+1}}{\lambda_t}(1-\delta_n)\left(\frac{\partial Y_{t+1}}{\partial n_{t+1}} - w_{t+1} + \frac{k}{\lambda_{t+1}\psi_{t+1}}\right)\right] \tag{28}$$

4.3. Equilibrium

This paper presents the equilibrium solution. However, for the purpose of simulation analysis, a linear approximation is used, which is presented here. The deviation of a variable x_t from its steady-state value x is denoted by $\tilde{x}_t$, while $\hat{x}_t$ represents the percentage deviation of x_t from its steady-state value.

To account for unemployment benefits b_t^u, the capital accumulation equation is modified as follows.

$$K_{t+1} = w_t l_t + r_t K_t + (1-\delta)K_t + b_t^u(1-l_t) - T_t - c_t. \tag{29}$$

The unemployment rate is given by $1 - l_t$, and the total amount of unemployment benefits is $b_t^u(1-l_t)$. It is assumed that these unemployment benefits are financed through a lump-sum tax T_t. The budget constraint related to these unemployment benefits is expressed as follows.

$$b_t^u(1-l_t) = T_t. \tag{30}$$

Taking equation (30) into account, the capital accumulation equation (29) becomes equation (2). It is assumed that the level of unemployment benefits is a fixed proportion of the wage level.

$$b_t^u = \mu w_t, 0 < \mu < 1. \tag{31}$$

At this point, the wage determination equation (27) is given as follows.

$$(1-\xi)(1-\mu)w_t - \frac{\xi \psi_t k}{\lambda_t} = \xi(Y_t - w_t - r_t K_t) \tag{32}$$

The following presents the linear approximations.

・Euler equation for consumption：Considering (3), we obtain the following equation.

$$\hat{c}_{t+1} = \frac{1}{\gamma}\frac{\hat{r}_{t+1} r}{r+1-\delta} + \hat{c}_t \tag{8}$$

・Capital accumulation：Considering (2), we obtain the following equation.

$$\hat{K}_{t+1} = \frac{l}{K} w \hat{w}_t + \frac{l}{K} w \hat{l}_t + r\hat{r}_t + (r+1-\delta)\hat{K}_t - \frac{c}{K}\hat{c}_t \tag{9}$$

・GDP：Considering (4), we obtain the following equation.

$$\hat{Y}_t = \theta \hat{K}_t + (1-\theta)\hat{l}_t \tag{10}$$

・Interest rate：Considering (6), we obtain the following equation.

$$\hat{r}_t = (\theta - 1)\hat{K}_t + (1-\theta)\hat{l}_t \tag{12}$$

・Employment rate: Considering (17), we obtain the following equation.

$$\hat{l}_t = (1-\delta_n)\hat{l}_{t-1} + \delta_n \hat{M}_t \tag{33}$$

・Matching function：Considering (18), we obtain the following equation.

$$\hat{M}_t = \alpha \hat{U}_t + (1-\alpha)\hat{V}_t \tag{34}$$

・The job-filling rate per vacancy：Considering (18), we obtain the following equation.

$$\hat{L}_t = \hat{M}_t - \hat{V}_t \tag{35}$$

・Unemployment rate：Because of $U_t = 1 - l_t$, we obtain the following equation.

$$\hat{U}_t = -\frac{l}{1-l}\hat{l}_t \tag{36}$$

・The job vacancy rate (labor market tightness)

$$\hat{\psi}_t = \hat{V}_t - \hat{U}_t \tag{37}$$

・Wage determination：Considering (32), we obtain the following equation. $C = \frac{\psi k}{\lambda}$ is defined.

$$\frac{(1-\xi)(1-\mu)w}{rK}\hat{w}_t - \frac{\xi C}{rK}\hat{\psi}_t + \frac{\xi C}{rK}\hat{\lambda}_t = \xi\left(\frac{Y}{rK}\hat{Y}_t - \frac{w}{rK}\hat{w}_t - \hat{r}_t - \hat{K}_t\right) \tag{38}$$

・The equation determining the probability of new hires：Considering (28), we obtain the following equation. $D = \frac{k}{\lambda L}$ is defined.

$$-\hat{\lambda}_t - \hat{L}_t = \hat{\lambda}_{t+1} - \hat{\lambda}_t + \frac{(1-\theta)A\theta\left(\frac{K}{l}\right)^{\theta}\left(\hat{K}_t - \hat{l}_t\right) - w\hat{w}_{t+1} - D\left(\hat{\lambda}_t + \hat{L}_t\right)}{\frac{D}{\rho(1-\delta_n)}} \tag{39}$$

・Marginal utility of consumption

$$\hat{\lambda}_t = -\gamma \hat{c}_t \tag{40}$$

The variables at the steady state are shown as follows.

$$r = \frac{1}{\rho} + \delta - 1 \tag{14}$$

$$w = \frac{\xi\left(C + l\left(A\left(\frac{K}{l}\right)^{\theta} - r\frac{K}{l}\right)\right)}{(1-\xi)(1-\mu) - \xi} \tag{15}$$

$$\frac{K}{l} = \left(\frac{r}{\theta A}\right)^{\frac{1}{\theta-1}} \tag{16}$$

$$\frac{c}{K} = w\left(\frac{K}{l}\right)^{-1} + r - \delta \tag{17}$$

Given that the unemployment rate in recent years has remained around 2%, the steady-state level of labor supply is set to $l = 0.98$.

The parameters are set as follows.

$\gamma = 1.5$	Eguchi (2011)
$\delta = 0.05$	Eguchi (2011)
$\theta = 0.3$	Recent capital income share
$\rho = 0.99$	Eguchi (2011)
$\delta_n = 0.15$	Based on the recent separation rate, we set[7]

Table.3: Parameter setting

As in Section 3, the remaining parameters are determined through calibration.

	Pre Distribution			Post Distribution		
	Mean	Distribution	Standard dev	Mean	Confidence interval	
ξ	0.250	Normal	0.1	0.2585	0.1070	0.4025
α	0.5	Normal	0.1	0.5058	0.3427	0.6727
A	1.0	Normal	0.1	0.9961	0.8341	1.1622
C	3.0	Normal	0.1	3.0013	2.8352	3.1651
D	1.0	Normal	0.1	1.0000	0.8364	1.1626

Table.4：Parameter setting

The calibration method follows the same approach as in Section 3.

[7] Ministry of Health, Labour and Welfare (2023), "Overview of the 2022 Employment Trends Survey Results"

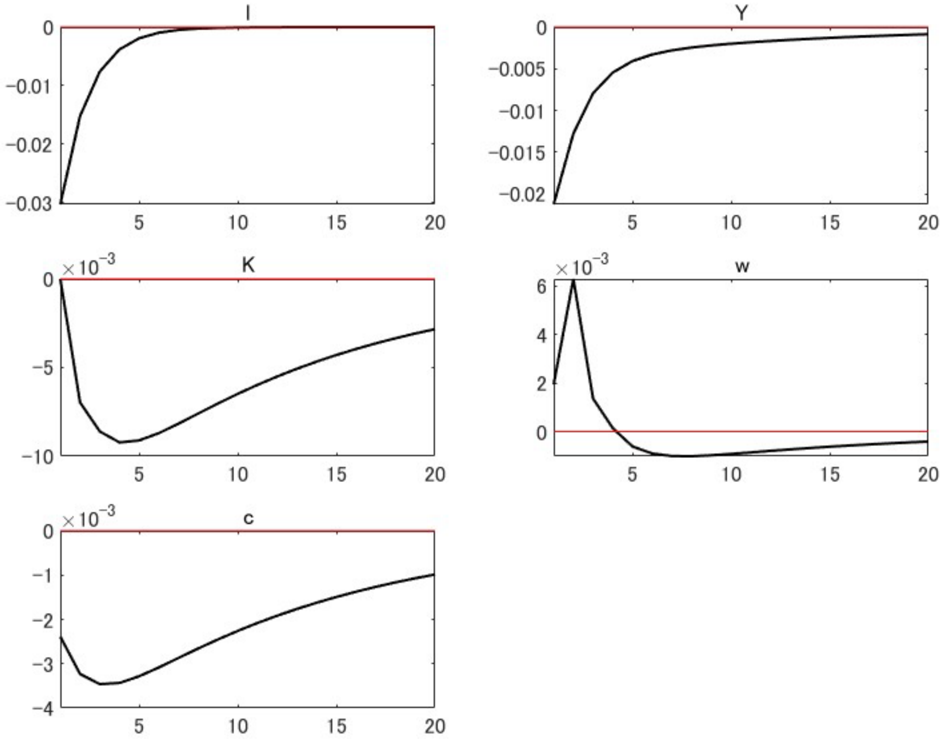

Fig.3：Case of No Unemployment Benefit（$\mu = 0$）

Figure 3 presents a simulation of the macroeconomic impact of labor force loss due to long COVID, assuming no unemployment benefits ($\mu = 0$). Fundamentally, the qualitative results are similar to those of a model that does not consider unemployment. Even if the labor force recovers, the simulation shows that it takes significantly longer for GDP to return to its original level. As for the wage rate, it increases at the initial stage, which can be attributed to the strong effect of reduced labor supply.[8]

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[8] To conduct the simulation of the model economy, equation (38) is input into the program with a one-period lag. As a result, a sharp increase in the wage rate appears in the second period; however, this should be interpreted as an actual wage increase in the first period.

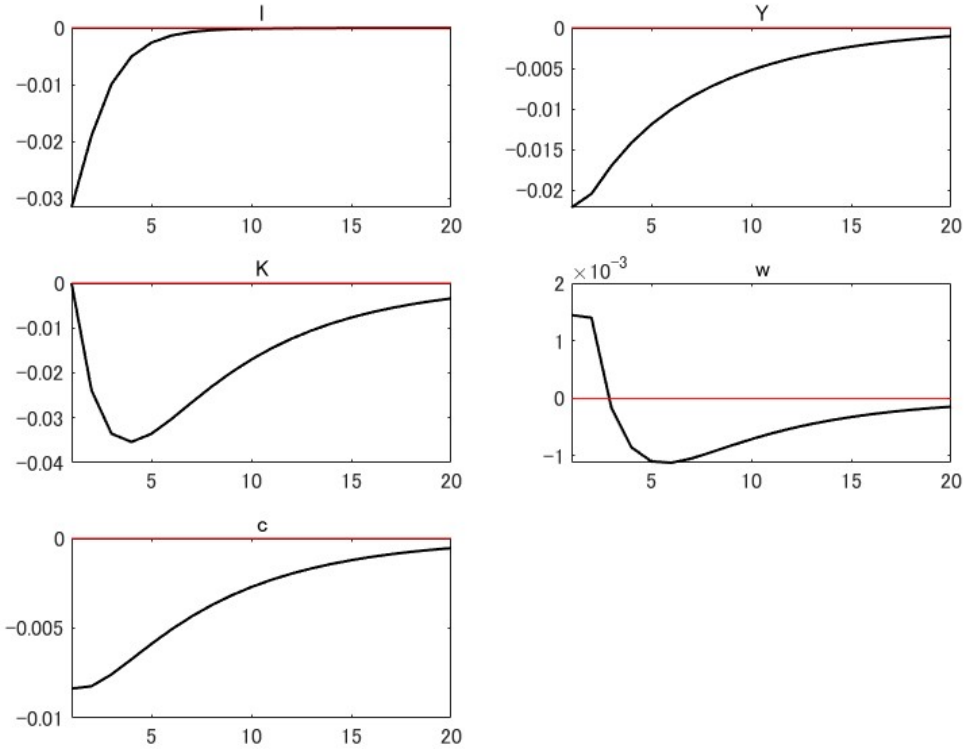

Fig.4：Case of Unemployment Benefit（μ =0.5）

Even when unemployment benefits are present, the qualitative dynamics remain unchanged: even if the labor force recovers, it still takes a considerably longer time for GDP to return to its original level. Compared to the case without unemployment benefits, the decline in wages is more pronounced. This can be attributed to a greater reduction in capital accumulation, which in turn lowers the marginal productivity of labor, resulting in a significant decline in the wage level.

5. Conclusions

In recent years, long COVID has become a significant social issue. Citing the WHO's definition, the Ministry of Health, Labour and Welfare of Japan states that "symptoms that continue for at least two months after infection with the novel coronavirus, and cannot be explained by other illnesses, are typically observed three months after the onset of infection." According to NHK reports, approximately 6% of those infected suffer from long COVID, and a hospital survey revealed that 54.1% of those individuals experience difficulty working. Based on these figures, it is estimated that around 3.2% of the total working population is unable to work fully.

This paper examined how such labor force loss due to long COVID affects the macroeconomy. A simulation using a model that does not account for unemployment revealed that a 3% decline in labor force reduces GDP by approximately 2%. It was also found that even if the extent of labor force loss diminishes, it takes considerable time for GDP to return to its original level. Furthermore, even when frictional unemployment is considered, the results suggest that GDP does not immediately return to its pre-shock level even after labor force recovery. These findings indicate that the effects of long COVID go beyond individual health concerns and may have medium- to long-term impacts on the labor market and economic growth.

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Program Code 1

```
//1. variables
var c K r w l Y;
varexo f;

//2. parameter
parameters rho delta A theta phi epsilon gamma;

//2.1 parametervalue
rho=0.99;
delta=0.05;
A=0.98;
theta=0.3;
gamma=1.5;
epsilon=0.5;
phi=0.5;

//3.equations
model(linear);
# rbar=1/rho+delta-1;
#         Klbar=(rbar/(theta*A))^(1/(theta-1)); % Kl denotes K/l
# wbar=(1-theta)*A*Klbar^theta;
#  cKbar=wbar*Klbar^(-1)+rbar-delta;  % cK denotes c/K
# lbar=0.98;

c(+1)=(1/gamma)*r(+1)*rbar/(1+rbar-delta)+c;
K=w(-1)*(1/Klbar)*wbar+l(-1)*(1/Klbar)*wbar+r(-1)*rbar+K(-1)*rbar+(1-delta)*K(-1)-cKbar*c(-1);
Y=theta*K+(1-theta)*l;
r=(theta-1)*K+(1-theta)*l;
w=theta*epsilon*(1-theta)*A*lbar/wbar*(K*Klbar-l)+(1-epsilon)*w(-1);
l = phi*l(-1)-f;
end;


//3. steady state check
steady;
check;

//4. simulation
shocks;
var f=0.0009;
end;

//5. results
stoch_simul(irf=20)l Y K w c;
```

Program Code 2

```
//1. variables
var c K r w l Y M U V L psi lambda u;
varexo f;

//2. parameter
parameters rho delta A theta phi xi gamma
alpha deltan C D mu;
//2.1 parametervalue
rho=0.99;
delta=0.05;
alpha=0.5;
A=1;
theta=0.3;
gamma=1.5;
xi=0.26;
phi=0.5;
C=3;
D=1;
deltan=0.15;
mu=0;

//3.equations
model(linear);
# lbar=0.98;
# Ubar=0.02;
# rbar=1/rho+delta-1;
#Klbar=(rbar/(theta*A))^(1/(theta-
1)); % Kl denotes K/l
#wbar=xi*(C+lbar*(A*Klbar^theta-
rbar*Klbar))/((1-xi)*(1-mu)-xi);
#  cKbar=wbar*Klbar^(-1)+rbar-delta;  %
cK denotes c/K
#Kbar=(rbar/(theta*A))^(1/(theta-
1))*lbar;
# Ybar=A*Kbar^theta*lbar^(1-theta);
c(+1)=(1/gamma)*r(+1)*rbar/(1+rbar-
delta)+c;
K=w(-1)*(1/Klbar)*wbar+l(-
1)*(1/Klbar)*wbar+r(-1)*rbar+K(-
1)*rbar+(1-delta)*K(-1)-cKbar*c(-1);
Y=theta*K+(1-theta)*l;
r=(theta-1)*K+(1-theta)*l;
(1-xi)*(1-mu)*wbar/(rbar*Kbar)*w-
xi*C/(rbar*Kbar)*(psi+lambda)=xi*(Yba
r/Kbar/rbar*Y-wbar/(rbar*Kbar)*w-r-K);
-lambda(-1)-L(-1)=lambda-lambda(-
1)+((1-
theta)*A*(Kbar/lbar)^(theta)*(theta*K(-
1)-theta*l(-1))-wbar*w-D*(lambda(-
1)+L(-1)))/
(D/(rho*(1-deltan)));
lambda=-gamma*c;
l=(1-deltan)*l(-1)+deltan*M+u;
M=alpha*U+(1-alpha)*V;
L=M-V;
U=-lbar/(1-lbar)*l;
psi=V-U;
u=phi*u(-1)-f;
end;

//3. steady state check
steady;
check;
//4. simulation
shocks;
var f=125;
end;
//5. results
stoch_simul(irf=20)l Y K w c;
```

Calibration Code 1

```
//1. variables
var c K r w l Y u Y_obs c_obs r_obs w_obs u_obs;
varexo uY uc ur uw uu Yf lf;

//2. parameter
parameters rho delta theta phi gamma, A, epsilon;

//2.1 parametervalue
rho=0.99;
delta=0.05;
%A=1;
theta=0.3;
gamma=1.5;
%epsilon=1;
phi=0.5;

//3.equations
model(linear);
# rbar=1/rho+delta-1;
#     Klbar=(rbar/(theta*A))^(1/(theta-1)); % Kl denotes K/l
# wbar=(1-theta)*A*Klbar^theta;
#  cKbar=wbar*Klbar^(-1)+rbar-delta;  % cK denotes c/K
# lbar=0.98;

c(+1)=(1/gamma)*r(+1)*rbar/(1+rbar-delta)+c;
K=w(-1)*(1/Klbar)*wbar+l(-1)*(1/Klbar)*wbar+r(-1)*rbar+K(-1)*rbar+(1-delta)*K(-1)-cKbar*c(-1);
Y=theta*K+(1-theta)*l-Yf;
r=(theta-1)*K+(1-theta)*l;
w=theta*epsilon*(1-theta)*A*lbar/wbar*(K*Klbar-l)+(1-epsilon)*w(-1);
l = phi*l(-1)-lf;
u=-lbar*l/(1-lbar);

%//3. steady state check
%steady;
%check;

Y_obs=Y+uY;
c_obs=c+uc;
r_obs=r+ur;
w_obs=w+uw;
u_obs=u+uu;
end;

estimated_params;
A, normal_pdf, 1, 0.1;
epsilon, normal_pdf, 0.5, 0.1;
stderr lf, inv_gamma_pdf,   0.1, inf;
stderr Yf, inv_gamma_pdf,   0.1, inf;
stderr uY, inv_gamma_pdf,   0.1, inf;
stderr uc, inv_gamma_pdf,   0.1, inf;
stderr ur, inv_gamma_pdf,   0.1, inf;
stderr uw, inv_gamma_pdf,   0.1, inf;
stderr uu, inv_gamma_pdf,   0.1, inf;
end;

varobs Y_obs c_obs r_obs w_obs u_obs;

estimation(datafile = jpdata, mode_check, mh_replic =500000, mh_nblocks =2, mh_drop =0.5, mh_jscale =0.5, bayesian_irf);
```

Calibration Code 2

```
//1. variables
var c K r w l Y M U V L psi lambda u Y_obs
c_obs r_obs w_obs u_obs;
varexo uY uc ur uw uu Yf uf;

//2. parameter
parameters rho delta A theta phi xi gamma
alpha deltan C D mu;

//2.1 parametervalue
rho=0.99;
delta=0.05;
%alpha=0.5;
%A=1;
theta=0.3;
gamma=1.5;
%xi=0.1;
phi=0.5;
%C=3;
%D=1;
%B=2;
deltan=0.15;
mu=0;

//3.equations
model(linear);
# lbar=0.98;
# Ubar=0.02;
# rbar=1/rho+delta-1;
#       Klbar=(rbar/(theta*A))^(1/(theta-
1)); % Kl denotes K/l
#       wbar=xi*(C+lbar*(A*Klbar^theta-
rbar*Klbar))/((1-xi)*(1-mu)-xi);
#  cKbar=wbar*Klbar^(-1)+rbar-delta;  %
cK denotes c/K
#       Kbar=(rbar/(theta*A))^(1/(theta-
1))*lbar;
# Ybar=A*Kbar^theta*lbar^(1-theta);

c(+1)=(1/gamma)*r(+1)*rbar/(1+rbar-
delta)+c;
K=w(-1)*(1/Klbar)*wbar+l(-
1)*(1/Klbar)*wbar+r(-1)*rbar+K(-
1)*rbar+(1-delta)*K(-1)-cKbar*c(-1);
Y=theta*K+(1-theta)*l-Yf;
r=(theta-1)*K+(1-theta)*l;
(1-xi)*(1-mu)*wbar/(rbar*Kbar)*w-
xi*C/(rbar*Kbar)*(psi+lambda)=xi*(Yba
r/Kbar/rbar*Y-wbar/(rbar*Kbar)*w-r-K);
-lambda(-1)-L(-1)=lambda-lambda(-
1)+((1-
theta)*A*(Kbar/lbar)^(theta)*(theta*K(-
1)-theta*l(-1))-wbar*w-D*(lambda(-
1)+L(-1)))/
(D/(rho*(1-deltan)));
lambda=-gamma*c;
l=(1-deltan)*l(-1)+deltan*M+u;
M=alpha*U+(1-alpha)*V;
L=M-V;
U=-lbar/(1-lbar)*l;
psi=V-U;
u=phi*u(-1)-uf;

Y_obs=Y+uY;
c_obs=c+uc;
r_obs=r+ur;
w_obs=w+uw;
u_obs=U+uu;
end;

estimated_params;
```

```
A, normal_pdf, 1, 0.1;
alpha, normal_pdf, 0.5, 0.1;
xi, normal_pdf, 0.25, 0.1;
C, normal_pdf, 3, 0.1;
D, normal_pdf, 1, 0.1;
stderr uf, inv_gamma_pdf,    0.1, inf;
stderr Yf, inv_gamma_pdf,    0.1, inf;
stderr uY, inv_gamma_pdf,    0.1, inf;
stderr uc, inv_gamma_pdf,    0.1, inf;
stderr ur, inv_gamma_pdf,    0.1, inf;
stderr uw, inv_gamma_pdf,    0.1, inf;
stderr uu, inv_gamma_pdf,    0.1, inf;
end;

varobs Y_obs c_obs r_obs w_obs u_obs;

estimation(datafile = jpdata, mode_check,
mh_replic    =500000,    mh_nblocks    =2,
mh_drop      =0.5,      mh_jscale      =0.5,
bayesian_irf);
```

Data for Calibration

```
data_q = [
-0.01739486	-0.00945570	0.32095219	-0.01040744	-0.06551780
-0.00199480	0.00352477	0.22202068	-0.00253243	-0.03452526
0.01846705	0.01166869	0.07944803	0.00425818	-0.03592997
0.01820352	0.00610249	-0.95134823	0.01347124	-0.08132892
-0.00423208	-0.01138582	-0.34756651	0.01403592	0.01413694
-0.01702362	-0.01178603	-0.01853931	0.00927702	0.07150269
0.00087472	-0.00755098	0.24472031	0.00682555	0.03965757
-0.00453104	0.00178760	0.14579469	0.00416578	0.05705823
-0.01322634	0.00390698	0.04455300	-0.00587760	0.09116295
-0.00688572	-0.00001006	0.00522906	-0.01465950	0.07086449
0.00627531	0.00345938	-0.09404873	-0.01668771	-0.00764149
0.01639579	0.00970070	0.17943072	-0.02017074	-0.04683438
0.02318975	0.01080033	-0.03038917	-0.01824654	-0.08644461
0.03205642	0.01099060	0.14282128	-0.00189377	-0.11129827
0.01466503	-0.00703832	-1.20057633	0.01303450	-0.08524518
-0.04873585	-0.02238075	1.51912037	0.01510981	0.08957761
-0.01371674	-0.00515689	1.01334134	0.00927276	0.10969893
-0.01914146	-0.01581633	0.82164979	0.00432450	0.06508478
-0.01169433	-0.00059359	0.63010149	-0.00295571	0.04979645
0.00157513	0.02110128	0.26682749	-0.00615613	0.03512189
-0.00214229	0.00908099	-49.49777821	-0.00428983	-0.00253509
0.00684518	0.00519863	3.04822224	-0.00164055	-0.00229348
0.00832388	0.00040198	-1.49340235	0.00082574	-0.03738537
0.01959580	0.01148010	0.09927530	0.00934569	-0.08347123
0.02149366	0.01545883	0.87146921	0.00264469	-0.18596010
0.01371811	0.01175990	-0.20301241	0.00620188	-0.13942937
-0.03219065	-0.03060619	-0.97390801	-0.00015486	0.05688455
-0.00877322	-0.01961062	-1.30327405	-0.00341783	0.09683814
0.00000366	0.00496805	1.03961744	-0.00370264	0.06206313
];
Y_obs = data_q(:,1);
c_obs = data_q(:,2);
r_obs = data_q(:,3);
w_obs = data_q(:,4);
```

```
u_obs = data_q(:,5);
```