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Tsubasa SHIBATA * and Hiroyuki KOSAKA**

March 2021

Abstract

In this study, we aim to develop the extended SIR model of epidemiology linked with the high-frequency multi-sector econometric model in order to investigate the impact of epidemic dynamics on the Japanese economy in Japan. Our approach features three aspects. The first one is that as for our epidemic model, we develop two time-varying parameters, namely an infection rate and a recovery/remote rate, which are crucial parameters in the conventional SIR model. Besides, these parameters are endogenized in our extended SIR model linked to the multi-sector econometric model, enabling to better understand the mechanism that infection and recovery rates increase or decrease as well as capture the changes of the epidemic behavior timely. The third one is that we construct the monthly econometric model that is composed of multi-sector industries. Our approach allows us to timely and exactly grasp the status of Japanese economy in respond to COVID-19 epidemic.

Keywords: COVID-19; SIR; Monthly Macro Econometric Model
JEL classification: F15, O14, O30

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In this study, we aim to develop the extended SIR model of epidemiology linked with the high-frequency multi-sector econometric model in order to investigate the impact of epidemic dynamics on the Japanese economy in Japan.

Our approach features three aspects. The first one is that as for our epidemic model, we develop two time-varying parameters, namely an infection rate and a recovery/remote rate, which are crucial parameters in the conventional SIR model. Besides, these parameters are endogenized in our extended SIR model linked to the multi-sector econometric model, enabling to better understand the mechanism that infection and recovery rates increase or decrease as well as capture the changes of the epidemic behavior timely. The third one is that we construct the monthly econometric model that is composed of multi-sector industries. Our approach allows us to timely and exactly grasp the status of Japanese economy in respond to COVID-19 epidemic.

By using our model, we prepared three scenarios to reassess the impact of the first state of emergency on the Japanese economy and the infection. The results of scenario simulation suggest that although the state of emergency measures has a certain effect on suppressing the increase in the number of infected people, the measure relying only on "self-restraint" has limited effects.

Keywords: COVID-19; SIR; Monthly Macro Econometric Model

JEL Classification: E17, I18

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1 Introduction

The COVID-19 pandemic has spread all over the world. In Japan, the first case of infection was identified in January 2020. Since then, Japan has been struggling to contain the spread of the infection. To prevent the explosive spread of the virus, the Japanese government declared the first state of emergency for 29 days from 7 April 2020, which requested the public to refrain from going outside unnecessarily and restaurants and shops to shorten hours of operation. The number of the infection had calmed down once. However, the state of emergency was implemented again on 14 January to cope with a surge of the infection. Now, the Japanese government has been extending the state of emergency for around two weeks in Tokyo and its neighboring prefectures. These policy measures against the COVID-19 lead to triggering a serious economic slowdown. Hence, policymakers and the public face a severe trade-off between economic activity and suppressing the infection.

In response to this situation, there are a number of studies to investigate the interaction between economic and epidemic outcomes. One approach is to integrate epidemiology, the Susceptible-Infected-Recovered (SIR) model into the macroeconomic model. The SIR model has been widely used to value and predict how the infection spreads across the population, proposed by Kermack and McKendrick (1927). From an economic perspective, Holtemoeller (2020) embeds the modified SIR model into the Solow model to analyze the effects of mitigation policies like lookdown and testing. Eichenbaum et al. (2020a, 2020b), Alvarez et al (2020), and Bognanni et al. (2020), etc. develop the integrated model of the SIR and dynamic optimization model. In studies focusing on the cases of Japan, Nakata and Fujii (2020) construct a model which enables to trace the interaction between SIR and macroeconomy in Japan. In particular, it is notable that although the conventional SIR model is assumed that infection and recovery rates which control the relationships among variables in the SIR model are constant, the extended SIR model which they develop has time-varying parameters, leading to capture the epidemic dynamics.

Going beyond these studies, we aim to develop the extended SIR model of epidemiology, which has time-varying parameters, linked to the monthly multi-sector econometric model. The infection and recovery rates in our SIR model are more structural in that they capture the reality that their rates are affected by individual decisions and policies. These approaches allow us to better understand the mechanism that infection and recovery rates increase or decrease as well as to capture the changes of the epidemic behavior. In addition, our economic model is the multi-sector econometric model. The whole model is a simultaneous equation system where production, price, wage, and demand for working time, consumption, investment, and import, allowing us to trace timely and exactly the economic spillover effects between COVID-19 epidemic and economy.

Then, by using our model, we simulated scenarios to reassess the impact of the first state of emergency on the Japanese economy as well as on the infection. As a result, we can find that although the state of emergency measures has a certain effect on suppressing the increase in the number of infected people, the policy measure relying only on "self-restraint" has limited effects.

The rest of the paper is organized as follows. In Section 2, we explain the theoretical framework of the extended SIR model and the high-frequency multi-sector econometric model. In Section 3, we explain data. Section 4 represents the empirical analysis. Finally, concluding remarks are provided in Section 5.

2 Model

Our model consists of two blocks: the epidemic block and the economic block. The epidemic model follows SIR which we modified. The economic model is the multi-sectoral econometric high frequency, monthly, model. The two blocks are linked through two variables: infectious persons I_t and the mobility of persons MV_t [1]. We illustrate the theoretical framework of each model block respectively below.

2.1 The Epidemic Model

The classical epidemic model SIR proposed by Kermack and McKendric (1927). The population N_t is classified into four categories at each time *t*: susceptible persons (no immunity) S_t, infectious persons I_t, and recovered persons R_t. How an epidemic transmission spreads over time is determined by these three states. Infection dynamics follows as:

$$S_t + I_t + R_t = N_t \tag{1}$$

$$S_{t+1} - S_t = -\beta S_t I_t \tag{2}$$

$$I_{t+1} - I_t = \beta S_t I_t - \gamma I_t \tag{3}$$

$$R_{t+1} - R_t = \gamma I_t \tag{4}$$

where β represents the effective transmission rate. γ denotes the remove rate or the recovery rate which is the number of people who go from being infected to recover or die. γ controls the transition of individuals from I to$R$. The force of infection is shown by two rates at which individuals acquire an infection, the transmission coefficient β and the fraction of infectious individuals γ.

In analyzing whether any pandemic occurs and how it calms down, it is crucial to obtain parameters: transmission rate β and removal rate/recover rate γ. In the conventional SIR model,

[1] We use data "Residential" in the Google mobility report. "Residential" shows category shows a change in the duration of time spent at home.

many of these models assume that β and γ are constant. However, constant β and γ may not hold in reality. Indeed, when the people reduced their contact with other persons during the lockdown and stay home, the number of infectious people began to decrease proportionally, implying that the infection rate decreased. Namely, as a result of various virus containment strategies, such as self-quarantine and social distancing mandates, the transmission and removal rates may vary over time. Therefore, our study attempts to get time-variant parameters β_t and γ_t which reflect the reality of the epidemic.

Here, we show that how we can derive time-varying parameters β_t and γ_t. We can express the number of susceptible persons S_t based on the original model as,

$$S_{t+1} - S_t = \beta_0 S_t I_t + \beta_1 PCR_t + \beta_2 MV_t + u_t \tag{5}$$

where PCR is the number of PCR tests and MV is the mobility of persons. β_0, β_1, and β_2 are parameters to be estimated. u_t is the error term. Then, we can rewrite equation (5) like:

$$S_{t+1} - S_t = \left(\frac{\beta_0 S_t I_t + \beta_1 PCR + \beta_2 MV + u_t}{S_t I_t}\right) S_t I_t$$

Here, we define time-varying infection rate β_t as follows:

$$\beta_t = \frac{\beta_0 S_t I_t + \beta_1 PCR + \beta_2 MV + u_t}{S_t I_t} \tag{6}$$

Similarly, we can obtain time-varying recover rate. The recovery rate can be explained as:

$$R_{t+1} - R_t = \gamma_0 I_t + \varepsilon_t \tag{7}$$

where γ_0 is a parameter and ε_t error the term. Then, the transmission equation of recovery can be rewritten as:

$$R_{t+1} - R_t = \left(\frac{\gamma_0 I_t + \varepsilon_t}{I_t}\right) I_t$$

We define a time-varying recovery rate as follows:

$$\gamma_t = \left(\frac{\gamma_0 I_t + \varepsilon_t}{I_t}\right) \tag{8}$$

In this study, our modified SIR model is as follows:

$$S_{t+1} - S_t = -\beta_t S_t I_t$$

$$I_{t+1} - I_t = \beta_t S_t I_t - \gamma I_t$$

$$R_{t+1} - R_t = \gamma_t I_t$$

$$\beta_t = \frac{\beta_0 S_t I_t + \beta_1 PCR_t + \beta_2 MV_t + u_t}{S_t I_t}$$

$$\gamma_t = \left(\frac{\gamma_0 I_t + \varepsilon_t}{I_t}\right)$$

In our model, β and γ are time-varying parameters and are endogenized, leading to capturing how β_t and γ_t are determined.

2.2 The High-Frequency Multi-Sectoral Econometric Model

Our economic framework extends to the multi-sectoral econometric model, based on a monthly quasi-two sector model by Kosaka (2017) [2] which consists of two-sector industries (manufacturing and service) production. We explain the specification of the model below.

2.2.1 Demand Side

The demand side consists of the determination of consumption, investment, and import.

2.2.1.1 Consumption

As for the demand side of the economy, private consumption is the most important for total output. We assume that household consumption is divided into durable consumer goods and non-durable consumer goods.

<u>Private Consumption of Non-Durable Goods</u>

Private consumption of non-durable goods cpr_{nd} is explained as:

$$cpr_{nd,t}/p_{cp,t} = a_0 + a_1\left(yd_t/p_{cp,t}\right) + a_3 d(I_t) \tag{9}$$

where yd_t denotes households' income and $p_{cp,t}$ consumption price index (CPI) at time *t*. Following the basis of classical consumer demand theory, the function for consumer expenditures on goods is explained by disposable personal income which is deflated in a consumer price index. In addition, the infection COVID-19 is included in this model, assuming that the COVID-19 has adversely affected the private consumption demand.

<u>Private Consumption of Durable Goods</u>

Private consumption of durable goods $cpr_{d,t}$ is formulated as follows:

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[2] In Kosaka (2017), the production consists of two sectors (manufacturing and service). Other economic decisions like consumption, price, wage, and factor demand for working time, are composed of one sector. In terms of this, the Kosaka model is a quasi-two sector model.

$$cpr_{d,t} = b_0 + b_1(yd_t/p_{cp,t}) + b_2(TOPIXF_t/p_{cp,t}) + b_3 d(I_t) \quad (10)$$

where $TOPIXF_t$ means The Tokyo Stock Price Index futures at time t, which reflects the current market capitalization as a benchmark for investment in Japanese Stocks. Since durable goods, motor vehicles and parts (furnishings and durable household equipment, etc.) can be assets, we take into consideration the relationships with the stock futures trading market. In this study, we consider the number of newly registered automobiles at a transport branch office in Japan as consumption of durable goods. We assume that the infection COVID-19 would give an impact on the consumption of durable goods by households like with the consumption of non-durable goods.

2.2.1.2 Private Domestic Investment

The gross private investment includes Residential Investment and Non-Residential Investment. We endogenize Residential Investment by utilizing new construction starts of housing data. Considering that housing investment is affected by housing speculation as well as the level of household's income, the private housing investment can be expressed by,

$$IHR_t = c_0 + c_1(yd_t/p_{cp,t}) + c_2(TOPIXF_t/p_{cp,t}) \quad (11)$$

where yd_t and $TOPIXF_t$ are deflated by $p_{cp,t}$ in order to eliminate the phenomenon of price change over time, leading to evaluating the economy in constant price.

2.2.1.3 Export/Import

<u>Import</u>

In this study, the export is assumed to be an exogenous variable. The import is explained by domestic demand as follows:

$$im_t = d_0 + d_1(cph_t + cg_t) \quad (12)$$

where cph_t is private consumption (total) and cg_t denotes government consumption.

<u>Exchange Rate</u>

We assume that the exchange rate is explained by the relative price and the interest rate differences between the home country and the United States as a benchmark, as well as the nominal current account per nominal total output as follows:

$$\ln e_t = f_0 + f_1 \ln\left(\frac{r_t^{us}/p_{x,t}^{us}}{r_t/p_{x,t}}\right) + f_2 \ln(r_t^{us} - r_t) + f_3\left((ex_t - im_t)/p_{x,t}X\right) \tag{13}$$

where e_t is the exchange rate, r_t is the nominal interest rate, r^{us} is the nominal U.S. interest rate, ex_t is the export, and im_t the import. $p_x X$ is the total output in the current price. $p_{x,t}^{us}$ is the total production price index of the United States, $p_{x,t}$ is the total production price index of the home country. In the short-term, fluctuation of the exchange rate depends on the effect of interest.

2.2.2 Supply Side

The supply side of the economy illustrates the producer's behavior: determination of sectoral production, sectoral factor demand, sectoral price, and sectoral wage rate.

2.2.2.1 Determination of Production

Manufacturing Industry

The manufacturing production is as follows:

$$\begin{aligned} \log xr_{i,t}^{IIP} = g_{i0} + g_{i1} \log cpr_{d,t} + g_{i2} \log cgr_t + g_{i3} \log ihr_t + g_{i4} \log ifr_t \\ + g_{i5} \log(imr_t/exr_{it}) + g_{i6} \log xr_{SV,t} + g_{i7} \log d(I_t) \end{aligned} \tag{14}$$

where $xr_{i,t}^{IIP}$ denotes the output of the *i*-th manufacturing industry at time *t*. The equation of manufacturing production in our monthly econometric model cannot hold strictly the identity relation of demand-supply of the national accounts. Hence, this formulation can be represented in the stochastic equation.

Following the basic concept of the identity relation of aggregate demand, we assume that $xr_{IIP,t}^{i}$ is explained by the private consumption of durable good $cpr_{d,t}$ the government consumption cgr_t, the private investment of housing ihr_t, the capital investment ifr_t, the relative trade of import imr_t to the export exr_t, and total production of service $xr_{SV,t}$. Additionally, we let the epidemic affect production by putting the infected persons I_t on this equation.

Service Industry

The service sector occupies approximately 70% of Japan's gross domestic product (GDP). The developments in this sector have a large impact on Japan's economy as a whole. In particular, the COVID-19 pandemic has significant impacts on the service sector. Therefore, we endogenize the production of the service industry. As with the production of manufacturing industry, the production of the service industry is as follows:

$$\log xr_{i,t}^{IPS} = h_{i0} + h_{i1}\log cpr_{nd,t} + h_{i2}\log cgr_t + h_{i3}\log ihr_t + h_{i4}\log ifr_t$$
$$+h_{i5}\log(imr_t/exr_t) + h_{i6}\log xr_{IIP,t} + h_{i7}\log d(I_t) \quad (15)$$

where $xr_{i,t}^{IPS}$ is the production of the *i*-rh service industry at time *t*. This model explains the impact of COVID-19 on the service sector.

2.2.2.2 Generalized Leontief Cost Function and Factor Demand

We consider the *KL* production function which can be used to describe domestic production behavior. In this study, we consider working time instead of labor in order to capture the change in the short-term. Hence, we assume H instead of *L*. The production function is given by:

$$X^S = f(H, K) \quad (16)$$

where H denotes working time and K is capital. The corresponding cost function to the production function (16) is defined as follows:

$$C = C(X^S, p_x, w, p_K) = w_h \cdot H + p_K K \quad (17)$$

where p_x is the production price index, p_K capital price, and w wage rate. Here, we assume that the Generalized Ozaki cost function following Nakamura (1990), which includes a generalization of Leontief cost function (Fuss, 1977) as a special case.

$$C(p, y, tm) = \sum_i \sum_j h_{ij}(y, tm)\sqrt{p_i}\sqrt{p_j} \quad (18)$$

where y refers to the level of total output, and tm time trend to capture effects of technical change. The specification represents flexible in the price, and treats scale effects and technical change. Assuming $h_{ij}(y, tm) = b_{ij}y^{b_{yi}}e^{b_{tm}tm}$, $h_{ii}(y, tm) = b_{ii}y^{b_{yi}}e^{b_{ti}tm}$, and $i = w, p_K$, the cost function can be rewritten as:

$$C(w, p_K, y, tm) = \begin{pmatrix}\sqrt{w} & \sqrt{p_K}\end{pmatrix}\begin{pmatrix} b_{ww}y^{b_{yw}}e^{b_{tmw}tm} & b_{wK}y^{b_y}e^{b_{tm}tm} \\ b_{Kw}y^{b_y}e^{b_{tm}tm} & b_{KK}y^{b_{yK}}e^{b_{tmK}tm}\end{pmatrix}\begin{pmatrix}\sqrt{w} \\ \sqrt{p_K}\end{pmatrix} \quad (19)$$

Applying the Shephard's Lemma, we obtain the following factor demand function as:

$$\frac{\partial C(w, p_K, y, tm)}{\partial w} = H = b_{ww}y^{b_{yw}}e^{b_{tmw}tm} + b_{Kw}y^{b_y}e^{b_{tm}tm}\sqrt{\frac{p_K}{w}}$$

$$\frac{\partial C(w, p_K, y, tm)}{\partial p_K} = K = b_{KK} y^{b_{yK}} e^{b_{tmK} tm} + b_{Kw} y^{b_y} e^{b_{tm} tm} \sqrt{\frac{w}{p_K}}$$

Since this model is a non-linear system that makes it difficult to estimate, we neglect the terms of case $i \neq j$ in h_{ij} of equation (19).

$$H = b_{ww} y^{b_{yw}} e^{b_{tw} tm} \tag{20}$$

$$K = b_{KK} y^{b_{yK}} e^{b_{tmK} tm} \text{ [3]} \tag{21}$$

Here, we extend into a multi-sector model with a time-index. Besides, we assume that the total output $y = (xr_t^{IPP} xr_t^{IPS})^{1/2}$ and then take the logarithm of both sides (20) and (21) for estimation as:

$$\log h_{i,t} = a_{i0} + a_{i1} \log(xr_t^{IPP} xr_t^{IPS})^{1/2} - a_{i2} tm_t \tag{22}$$

where $h_{i,t}$ is the working time of the *i*-th industry, xr_t^{IPP} an aggregate index of industry production, and xr_t^{IPS} an aggregate of the tertiary industry at time *t*. Furthermore, we modify the equation (21) in order to take into account the effect of epidemic COVID-19 on factor demand as follows:

$$\log h_{i,t} = a_{i0} + a_{i1} \log(xr_t^{IPP} xr_t^{IPS})^{1/2} - a_{i2} tm_t + a_{i3} \log(I_t) \tag{23}$$

Equation (23) is applied for empirical estimation.

2.2.2.3 Sectoral Price

Our model includes producing price index, consumer price index, export price index, and import price index. In this study, the producing price index is endogenized. The mechanism of determining producing price index is assumed to follow profit maximization.

Producers attempt to set the price to maximize their profits under imperfect competition. In this study, in order to reflect stickiness, we assume the modified profit maximization problem as:

$$\max_{p_{i,t}} \quad \tilde{\pi}_{p_i} = \max_{p_i} \left\{ -\frac{1}{2} c_{i0} \left(p_t^i - c_{i1} p_{t-1}^i - \tilde{c} \right)^2 + \frac{1}{\overline{X}_t} \left(p_{x,t} X_t^D - C_{i,t} \right) \right\} \tag{24}$$

where $\tilde{\pi}_{p_i}$ denotes the modified profit function of the *i*-th industry, X_t^D the aggregate demand,

[3] Due to data availability of capital price, our model doesn't treat capital demand model.

and $\overline{X_t}$ the standard level of production. We add the quadratic loss term of $-1/2\, c_0\left(p_t^i - c_1 p_{t-1}^i - \tilde{c}\right)^2$, which enables the model to capture reality that firms are unwilling to have a significant change in the price. b_0^k, b_1^k, and $\tilde{b}^k$ are unknown parameters to be estimated.

The first-order condition for maximizing profits yields,

$$\frac{\partial \tilde{\pi}_{p_i}}{\partial p_{i,t}} = -c_{i0}\left(p_{i,t} - c_{i1}p_{i,t-1} - \tilde{c}\right) + \frac{1}{\overline{X_t}}\left(p_{x,t}\frac{\partial X_t^D}{\partial p_{i,t}} + X_t^D - MC_{i,t}\frac{\partial X_t^S}{\partial p_{i,t}}\right) = 0 \tag{25}$$

where $MC_{i,t}$ represents the marginal cost of the *i*-th industry. We assume $\partial \overline{X}_t/\partial p_t^k = 0$. Rearranging equation (25) in regard to $p_{i,t}$, we can obtain the optimal price as follows:

$$p_{i,t} = \tilde{c} + c_{i1}p_{i,t-1} + \frac{1}{c_0\overline{X_t}}\left(X_{i,t}^D + p_t^i\frac{\partial X_t^D}{\partial p_{i,t}} - MC_{i,t}\frac{\partial X_t^S}{\partial X_t^D}\frac{\partial X_t^D}{\partial p_{i,t}}\right) \tag{26}$$

where $\partial X_{D,t}^k/\partial p_t^k$ is the price elasticity of demand. Price elasticity of demand needs information on the form of the demand curve that households have. However, it is difficult for producers to know the exact demand curve of households. Hence, we adopt the subjective demand function approach (or perspective demand function) by Negishi (1961). In the subjective demand curve approach, the firms conjecture the demand curve since they don't have full information on it. In terms of this, the producers have some extent arbitrary of setting price elasticity of the demand. In this study, assuming that $\partial X_t^D/\partial p_{i,t} = -\varepsilon_i\left(1/p_{i,t}\right)$ and $\partial X_t^S/\partial X_t^D = \delta_i p_{i,t}$ $(\delta_i > 0)$, we obtain the following equation.

$$p_{i,t} = \tilde{c} + c_{i1}p_{i,t-1} + \frac{1}{c_{i0}}\left(\frac{X_t^D}{\bar{X}}\right) - \frac{\varepsilon_i}{c_{i0}}\left(\frac{1}{\bar{X}}\right)(1 - \delta MC_{i,t}) \tag{27}$$

Assuming $\bar{X} = X^D$, the sectoral price can be rewritten as:

$$p_{i,t} = \left(\tilde{c} + \frac{1}{c_{i0}}\right) + c_{i1}p_{i,t-1} - \frac{\varepsilon_i}{c_{i0}}\left(\frac{1}{X_t^D}\right) + -\frac{\varepsilon_i\delta_i}{c_{i0}}\left(\frac{MC_{i,t}}{X_t^D}\right) \tag{28}$$

where we assume $X_t^D = \left(xr_t^{IPP}xr_t^{IPS}\right)^{1/2}$for empirical analysis. This specification implies that the price rises when demand increases and $MC_{i,t}/X_t^D$ increases. $MC_{i,t}$ is derived from the cost function (23).

2.2.2.4 Sectoral Wage

Producers also determine wage rates while they maximize their profits. Therefore, we assume that the optimum wage rate will be determined under the profit maximization problem. We modify the profit function $\tilde{\pi}_{w,t}^i$ as follows:

$$\max_{w_i} \quad \tilde{\pi}_{w_i} = \max_{w_i}\left\{-\frac{1}{2}d_{i0}\left(w_{i,t} - d_{i1}p_{cp,t} - d_{i2}\right)^2 + \frac{1}{\bar{X}}\left(p_{x,t}X_t^D - C_t^i\right)\right\} \tag{29}$$

where d_{i2} means the level of the minimum wage rate. The first component, $\left(w_t^i - i_1 p_{cp,t} - i_2\right)^2$, shows that firms take into consideration the minimum wage rate and price level in markets.

The first-order condition for maximizing profits yields,

$$\frac{\partial \tilde{\pi}_{w_i}}{\partial w_{i,t}} = -d_{i0}\left(w_{i,t} - d_{i1}p_{cp,t} - d_{i2}\right) - \frac{1}{\bar{X}}\frac{\partial C_t^i}{\partial w_{i,t}} = 0 \tag{30}$$

Assuming $\bar{X} = X$, we obtain the following equation.

$$w_t^i = d_{i2} + d_{i1}p_{cp,t} - \frac{1}{d_{i0}}\frac{1}{X/L_t^i} \tag{31}$$

This equation explains that the wage rates depend on the level of the consumer price index and labor productivity.

3 Data

This study utilizes monthly data from various data sources to develop a monthly sectoral Japanese econometric model. The epidemiology model SIR we modified uses daily data.

Macroeconomic Data

The macroeconomic variables in this study include an index of industrial production, index of tertiary (service) production, private consumption of durable and non-durable goods, private investment of housing and capital, import, and export. Monthly indices of industry and tertiary (service) production are published from the Ministry of Economy, Trade and Industry in Japan. They are the 2015-based year and seasonally adjusted. The industry classification used in our model is shown in Table 1.

=== Table 1 ===

=== Table 2 ===

As for the private consumption of durable, we substitute the number of new passenger cars registered in Japan, which is published by the Japan Automobile Dealers Association. The data of non-durable private consumption is the number of monthly sales published by the Japan Department Stores Association and by the National Supermarket Association of Japan.

Next, we suppose that the number of housing starts could reflect the current condition of private residential investment. Hence, we utilize historical new construction starts of housing data which comes from the Ministry of Land, Infrastructure, Transport, and Tourism. The capital investment is substituted for the number of machinery orders from the private sector published by the Economic and Social Research Institute Cabinet Office, Japanese Government.

Price in our model are data of producer price indices and services producer price indices which come from Bank of Japan, consumer price index published in Statics Bureau of Ministry of Internal Affairs and Communications in Japan. The industry classification of producer price indices and services producer price indices corresponds to the classification of the indexes of industrial production, the index of tertiary (service) production.

The data by the industry of wage, employment, and working time come from Monthly Labour Survey published in Ministry of Health, Labour and Welfare in Japan. Our model uses their data about establishments with 30 or more regular employees. The industry classification of these data corresponds to classification of the indexes of industrial production, the index of tertiary (service) production. Then, the data of the long-term interest rate (10 Year's government bonds yields) of the US is gathered from the Federal Reserve Bank of St. Louis database.

Our model uses the Tokyo Stock Price Index (TOPIX) as the benchmark of the stock price in Japan. We download it from Yahoo Finance. As for data of trade (export/import), the import and export index (quantum) published by Trade Statistics of Japan is utilized in our model.

The COVID-19 Data

We use all data about SIR from the Ministry of Health, Labour and Welfare in Japan: the number of new positive PCR test cases, the number of recoveries from COVID-19, and the number of deaths due to COVID-19. We also utilize COVID-19 Community Mobility Reports by Google to grasp people's activity in response to before and after COVID-19. In particular, we use data "Residential" in the Google mobility reports. "Residential" shows category shows a change in the duration of time spent at home.

4 Empirical Results

4.1 Estimation Results

As for our economic model, the sample period is from the period January 2016 to October 2020, including 58 observations. Also, the extended SIR model is for January 1, 2020-December 31, 2020. In the framework, most equations are estimated by applying ordinary least squares. The others are estimated by assuming the Auto-regressive model AR(1), which depends linearly on its previous values and stochastic term. In this section, the results of the estimation and final test are shown. We show several estimation results about crucial variables below.

The Extended SIR Model

Tables 3 and 4 represent the estimated results of the SIR model. We run ordinal least squares to estimate them. In Table 3, the estimated result of equation (5) is shown. We can see the valid relation between $(I_{t+1} - I_t)$ and S_t*I_t. Although a change in the duration of time spent at home (the Google mobility reports) might be less statistically significant, the result is well estimated. We conclude that it is acceptable. Table 4 displays the result of equation (7). We can see the correlation between the number of recovered/removed persons and infectious persons. This is well estimated.

=== Table 3 ===

=== Table 4 ===

Transmission Rate $\boldsymbol{\beta_t}$ and Recovery/Remove Rate $\boldsymbol{\gamma_t}$

We can calculate the time-variant parameters of the effective transmission rate $\beta_t$and the recovery/remove rate γ_t by using estimated parameters, following equations (6) and (8) respectively. Figures 1 and 2 display estimated parameters β_t and γ_t.

=== Figure 1 ===

Here, considering the relation of $I_{t-1} - I_t = \beta S_t I_t - \gamma_t I_t$ in equation (3), $\beta S_t - \gamma$>0 implies that the epidemic transmission spreads. In the contrast, $\beta S_t - \gamma$<0 means that infection tends to calm down. Hence, we can see $\beta S_t - \gamma_t$ as an increasing or decreasing index of the infection. Figure 2 represents $\beta S_t - \gamma$. During the first state of emergency, the line is the downward-slope. It implies that the infection is decreasing. However, the positive values mean that the epidemic doesn't tend to settle down enough yet.

=== Figure 2 ===

Economic Model

Several estimation results about crucial variables are shown. Tables 5 displays the estimation results of the producer price index of the transport equipment industry. Tables 5, 6, and 7 display the estimation results of the index of tertiary production: accommodations, eating and drinking Services, and amusement services respectively. The results suggest that there is a valid relationship between the number of infectious persons and production. In particular, comparing with coefficients about the number of infectious persons among these industries, we can see that the spread of COVID-19 affects accommodation and amusement service much more negatively.

We estimated all equations, following the framework in the previous section. Some results for stochastic equations, which are not sufficiently satisfactory or show a wrong sign, are modified or excluded from our system.

=== Table 5 ===

=== Table 6 ===

=== Table 7 ===

=== Table 8 ===

4.2 Final Test

We conducted the final test in order to evaluate the accuracy of our whole system. Some stochastic equations, which worse the performance of the overall system, are excluded from our system, leading to being treated as exogenous variables[4]. As a result, our simultaneous economic system liked with the extended SIR model consists of 380 simultaneous equations. The modified SIR model includes 7 endogenous equations, where three equations are S_t, I_t, and R_t, two equations are β_t and γ_t, and the other two are equations bridging two models.

The overall performance of these variables is acceptable. Thus, the estimated results suggest that our theoretical approach has grasped.

It is a challenge to capture the high-frequency fluctuations and to link with two models with different time-periods (monthly-daily). Thus, we conclude that this whole system is acceptable as the first step of our research.

4.3 Scenario Analysis

Now, Japan is under the second state of emergency. Japanese are urged to refrain from going outside unnecessarily and restaurants and shops are asked to shorten their opening hours. This has enabled us to avoid an explosive rise in the number of infections and to suppress surging coronavirus cases. However, the pace of decline has been slowing down. Some ask if self-restraint has worked to prevent the further spread of infections.

In order to reassess the impact of the state of emergency on the Japanese economy as well as the infection, we focus on the first state of emergency. We prepared three scenarios.

Scenario 1: It is assumed that the first state of emergency was implemented until 31 July, on the condition that more strictly self-restraint is imposed until 30 June, and then self-restraint at the level as it was (the first state of emergency that we experienced)

[4] Import is exogenous in our model.

is implemented until 31 July 2020.

Scenario 2: It is assumed that the first state of emergency imposed more strictly self-restraint is implemented until 30 June 2020.

Scenario 3: It is assumed that the state of emergency (self-restraint) at the level as it was (the first state of emergency that we experienced) was extended until 31 July 2020.

Scenario 1 is the most severe self-restraint measures among the three scenarios. All three scenarios are simulated from May 2020 to October 2020[5]. Several crucial results about the three scenarios simulation are shown below.

COVID-19 Infection

Figure 3 shows that each scenario simulation leads to changes in the duration of time staying at home. Under these different conditions by scenario, Tables 4, 5, and 6 illustrate changes in the number of susceptible persons, infectious persons, and recovered persons, respectively.

=== Figure 3 ===

We can see that scenario 1 among scenarios can prevent the spread of infection effectively. Table 9 represents that strict self-restraint like scenarios 1 and 2 may enable to decrease around three hundred infectious persons more than actual values. On the contrary, the results of scenario 3 in Table 9 suggest that even if the state of emergency was extended to July, the monthly reduction of infectious persons is at most less than two hundred.

=== Table 9 ===

=== Table 10 ===

=== Table 11 ===

The Economy

Next, we look at an impact on the economy. Table 12 reports the impacts of the reduction of infections by the enhanced state of emergency on the production of manufacturing and service industries. Manufacturing industries recover after July whereas production of service industries falls in all time periods. One reason for the earlier recovery of manufacturing industries is that the reduction of infectious people has a positive impact on economic activity. However, service industries that rely heavily on in-person interaction tend to continue suffering from the negative economic impact of the COVID-19.

[5] Due to data unavailability, we could not simulate analysis after October 2020.

=== Table 12 ===

Furthermore, seeing results by sector, the situation varies. Production of iron and steel industry, one of the key industries in Japan, falls from 2 percent to more than 3 percent at worst under all three scenarios. Production of transport equipment also falls because the demand for mobility is decreasing by public transportations. In contrast, the production of Information and Communication Electronics Equipment increase the production. This is because remote-working and remote-learning increase demand for utilization of electronic communication, leading to increasing the production of information and communication electronics equipment.

=== Table 13 ===

Next, Table 14 shows economic impact of the state of emergency by scenario on production of service industries. It is obvious that accommodation, eating and drinking service, and amusement services, which rely heavily on face-to-face communication or physically close-contact, suffer from significant negative impacts.

=== Table 14 ===

In Table 15, we can see how great the level of the state of emergency give an economic impact on private consumption. Consumption of non-durable goods of supermarket shows positive values. There are two reasons. One is that the supermarkets are classified as an "essential service" for our daily life. The other is that they have introduced and expanded their online delivery service which allows shopping at home.

=== Table 15 ===

Table 16 shows that the working time of information and communication service increases whereas accommodation and eating and drinking service decline. These results suggest that introducing remote-work and remote-learning stimulate demand for information and communication service. Besides, Table 17 reports the impacts of state of emergency measures on wage rate by sector. Although manufacturing and service industries have negative impacts on their wages, the wage rate of retail trades rises.

=== Table 16 ===

=== Table 17 ===

Considering simulation results, it is found that strengthening or prolonging the state emergency that requests “self-restraint” is effective to some extent to prevent the spread of the infection.

On the other hand, the economic impacts of the implementation of emergency measures consistent a decline in production growth and consumption. However, its economic impacts vary across industries and firms. As for production, service industries are directly affected by containment measures. In particular, the accommodation, food service, and amusement services sectors, which rely heavily on physically close contact, undergo a significant negative impact. The related industries to service sectors like transport equipment manufacturing, also affect production negatively. In contrast, remote-working and remote learning stimulate the demand for communication equipment, resulting in a great increase in the production of related manufacturing industries. Thus, as negative impacts are offset by positive ones each other, the severe economic slowdown hardly appears in the macroeconomic data explicitly.

However, considering not much difference among scenarios, our simulation results suggest that the measure relying only on “self-restraint” has limited effects. It would be difficult to reduce the infection rate anymore as long as we haven’t had any ways to dies out the infection completely yet. Thus, we think that we are required to promoting more effective measures with various aspects: increasing supplies of vaccines promptly, enhancing active epidemiological surveys, strengthening PCR tests, and increasing bed capacity.

5 Conclusion

This study constructed Japan’s econometric model linked to the extended epidemic SIR model. By implementing scenario simulation analysis, we investigated the effect of the state of emergency that relies on “self-restraint”. The findings are summarized as follows:

1. As for production, service industries are directly affected by containment measures. In particular, the accommodation, food service, and amusement services sectors, which rely heavily on physically close contact, undergo significant negative impacts. The related industries to service sectors like transport equipment manufacturing, also affect production negatively.
2. In contrast, remote-working and remote learning stimulate the demand for communication equipment and its service, resulting in a great increase in the production of related manufacturing industries and service industries.
3. The state of emergency measures has a certain effect on suppressing the increase in the number of infected people. However, considering not much difference among scenarios, our simulation results suggest that the measure relying only on “self-restraint” has limited effects.

Thus, our system constructed the monthly multi-sectoral econometric model linked to the extended epidemic SIR. We also examined the effect of the first state of emergency implemented in April 2020. However, our model requires some improvements. First, infection and recovery rates should be modified to be more structural to explain the effect of other policy measures like increasing supplies of vaccines, enhancing active epidemiological surveys, strengthening PCR tests, and increasing bed capacity. Second, we should extend this model to improve its applicability to policy analysis theoretically and empirically. Our approach is just getting started. In the future, improving this model would become a more powerful tool and give us better guidance to understand the interaction between epidemic behavior and economic decisions.

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Table 1. Industry Classification of Index of Industry Production

	Industry Classification
00-00-00	Total
02-00-00	Mining
03-00-00	Manufacturing
03-01-00	Iron and Steel
03-02-00	Non-Ferrous Metals
03-03-00	Metals
03-04-00	Production Machinery
03-05-00	General-Purpose Machinery
03-06-00	Business Oriented Machinery
03-07-00	Electronic Parts and Devices
03-08-00	Electronic Machinery
03-09-00	Information and Communication Electronics Equipment
03-10-00	Transport Equipment
03-11-00	Ceramics, Stone and Clay Products
03-12-00	Chemicals
03-13-00	Petroleum and Coal Products
03-14-00	Plastic Products
03-15-00	Pulp, Paper and Paper Products
03-16-00	Foods and Tobacco
03-17-00	Other Manufacturing
03-17-01	Textile Products
03-17-02	Wood and Wood Products
03-17-03	Furniture
03-17-04	Printing
03-17-05	Rubber Products
03-17-06	Other Products

Table 2. Industry Classification of index of Tertiary Industry

	Industry Classification
00-00	Total
05-00	Electricity, Gas
06-00	Information and Communications
07-00	Transport and Postal Activities
07-01-00	Railway Transport
07-01-01	Railway Passenger Transport
07-01-02	Railway Freight Transport
07-02-01	Road Passenger Transport
07-02-02	Road Freight Transport
08_00	Wholesales
08-01	Textile and Apparel
08-02	Food and Beverages
08-03	Machinery and Equipment
09-00	Retail Trade
09-01	General Merchandise
09-02	Dry Goods, Apparel and Apparel Accessories
09-03	Food and Beverage
09-04	Machinery and Equipment
10-00	Finance and Insurance
11-00	Real Estate and Goods Rental and Leasing
12-00	Business-related Services
13-00	Accommodations
14-00	Eating and Drinking Services
15-00	Other Living-rerated and Persona Services
16-00	Amusement Services
17-00	Leaning Support
18_00	Medical, Health Care and Welfare
19_00	Compound Services and Other

Table 3. Estimation Result of Susceptible Equation: Sample 01/01/2020-12/31/2020

Explanatory Variables	Coefficient	S.E.
S_t*I_t	-1.37E-10***	7.46E-12
The number of PCR tests *(t-2)*	-0.032***	0.004
D(Google_ Residential)	15.297	9.275
Dummy_05082020	-804.758***	231.892
Dummy_Monday	222.182*	82.182
Dummy_Sunday	376.594***	83.073
Dummy_PCR	3486.406***	647.876
Observation		366
Adj. *R*-squared		0.861

Note: Adj. *R*-Squared is adjusted *R*-squared. *** $p < 0.001$, ** $p < 0.05$, and * $p < 0.1$, respectively.

Table 4. Estimation Result of Recovered Equation: Sample 01/01/2020-12/31/2020

Explanatory Variables	Coefficient	S.E.
I_t	0.011***	0.000
Dummy_05/08/2020	950.107***	121.425
Dummy_Tuesday	99.718**	47.166
Dummy_Wednesday	141.886**	46.831
Dummy_Thursday	117.508**	46.851
Dummy_Friday	156.451**	47.319
Constant	-81.666**	27.141
Observation		366
Adj. R-squared		0.815

Note: Adj. R-Squared is adjusted R-squared. *** $p < 0.001$, ** $p < 0.05$, and * $p < 0.1$, respectively.

Table 5. Index of Industrial Production: Transport Equipment Industry (Sample 2016M1-2020M10)

Explanatory Variables	Coefficient	S.E.
ln (Consumption of Durable Goods-Cars)	0.062	0.036
Δln (Private Housing Investment (*t*-1))	0.320*	0.166
Δln (Export Index (*t*-1)/Import Index (*t*-1))	0.052*	0.046
ln(Index of Production Transport Equipment (*t*--1))	0.766	0.055
Δln (Index of Tertiary production)	2.067***	0.349
Δln (Covid-19 Infectious Persons (-2))	-0.054***	0.010
Constant	0.313	0.416
Observation		58
Adj. R-squared		0.894

Note: Adj. R-Squared is adjusted R-squared. *** $p < 0.001$, ** $p < 0.05$, and * $p < 0.1$, respectively.

Table 6. Index of Tertiary production: Accommodations (Sample 2010M5-2020M10)

Explanatory Variables	Coefficient	S.E.
ln (Consumption of Non-Durable Goods (*t*-1)/CP I(*t*-1))	0.152*	0.087
Δ ln (Export Index/Import Index)	0.196***	0.056
ln (Index of Production Accommodations (*t*-1))	0.729***	0.048
ln (Index of Industrial Production)	0.560**	0.257
Δ ln (Covid-19 Infectious Persons (*t*-1))	-0.180***	0.015
Constant	-3.839**	1.608
Observation		126
Adj. R-squared		0.906

Note: Adj. R-Squared is adjusted R-squared. *** $p < 0.001$, ** $p < 0.05$, and * $p < 0.1$, respectively.

Table 7. Index of Tertiary production: Eating and Drinking Services (Sample 2010M5-2020M10)

Explanatory Variables	Coefficient	S.E.
ln (Consumption of Non-Durable Goods (*t*-1)/CPI (*t*-1))	0.058	0.057
Δ ln (Export Index/Import Index)	0.102	0.036
ln (Index of Production Eating and Drinking Services (*t*-1))	0.585***	0.064
ln (Index of Industrial Production)	0.448**	0.161
Δ ln (Covid-19 Infectious Persons (*t*-1))	-0.088***	0.009
Constant	-1.118	0.997
Observation		126
Adj. R-squared		0.826

Note: Adj. R-Squared is adjusted R-squared. *** $p < 0.001$, ** $p < 0.05$, and * $p < 0.1$, respectively.

Table 8. Index of Tertiary production: Amusement Services (Sample 2010M4-2020M10)

Explanatory Variables	Coefficient	S.E.
ln (Consumption of Non-Durable Goods(*t*-1)/CPI(*t*-1))	0.118*	0.064
Δ ln (Export Index/Import Index)	0.125**	0.041
ln (Index of Production Amusement Services (*t*-1))	0.741***	0.039
Δ ln (Covid-19 Infectious Persons (*t*-1))	-0.110***	0.011
Constant	-0.757	1.023
Observation		127
Adj. R-squared		0.828

Note: Adj. R-Squared is adjusted R-squared. *** $p < 0.001$, ** $p < 0.05$, and * $p < 0.1$, respectively.

Table 9. The Number of Susceptible Persons S

	Actuals	Scenario 1		Scenario 2		Scenario 3	
2020M05	126,111,835	126,112,213	(▲379)	126,112,213	(▲379)	126,111,988	(▲153)
2020M06	126,107,789	126,108,357	(▲568)	126,108,347	(▲558)	126,108,051	(▲262)
2020M07	126,081,643	126,082,213	(▲571)	126,081,998	(▲356)	126,081,997	(▲355)
2020M08	126,017,507	126,018,055	(▲548)	126,017,959	(▲453)	126,017,780	(▲274)
2020M09	125,983,596	125,984,274	(▲678)	125,984,149	(▲553)	125,983,938	(▲342)
2020M10	125,949,661	125,950,495	(▲834)	125,950,342	(▲681)	125,950,082	(▲421)

Note: Values in parentheses show differences from actual values.

Table 10. The Number of Infectious Persons: I

	Actuals	Scenario 1		Scenario 2		Scenario 3	
2020M05	16,973	16,640	(▲-333)	16,640	(▲-333)	16,816	(▲-157)
2020M06	18,721	18,338	(▲-383)	18,349	(▲-373)	18,536	(▲-186)
2020M07	36,088	35,803	(▲-286)	35,969	(▲-120)	35,883	(▲-205)
2020M08	68,088	67,867	(▲-221)	67,901	(▲-188)	67,974	(▲-115)
2020M09	83,179	82,879	(▲-301)	82,927	(▲-252)	83,009	(▲-170)
2020M10	100,762	100,399	(▲-364)	100,458	(▲-304)	100,559	(▲-204)

Note: Values in parentheses show differences from actual values.

Table 11. The Number of Recovered Persons: R

	Actuals	Scenario 1		Scenario 2		Scenario 3	
2020M05	14,333	14,255	(▲-79)	14,255	(▲-79)	14,304	(▲-30)
2020M06	16,522	16,331	(▲-191)	16,331	(▲-191)	16,440	(▲-82)
2020M07	25,253	24,974	(▲-280)	25,023	(▲-231)	25,110	(▲-143)
2020M08	57,130	56,783	(▲-347)	56,846	(▲-285)	56,951	(▲-179)
2020M09	75,708	75,277	(▲-431)	75,354	(▲-355)	75,483	(▲-226)
2020M10	91,877	91,341	(▲-536)	91,435	(▲-442)	91,594	(▲-283)

Note: Values in parentheses show differences from actual values.

Table 12. Percentage Deviation of Total Production from Baseline (%)

	(a) Manufacturing Industries			(b) Service Industries		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
2020M05	-0.496	-0.496	-0.480	-1.674	-1.674	-1.667
2020M06	-0.075	-0.074	-0.186	-1.414	-1.412	-1.539
2020M07	0.012	0.005	-0.097	-1.355	-1.365	-1.341
2020M08	0.020	0.000	0.053	-1.082	-1.094	-1.057
2020M09	0.106	0.105	0.145	-0.883	-0.872	-0.876
2020M10	0.195	0.204	0.213	-0.760	-0.762	-0.755

Table 13. Percentage Deviation of Sectoral Output from Baseline: Manufacturing Industries (%)

	(a) Iron and Steel			(b) Transport Equipment			(c) Information and Communication Electronics Equipment		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
2020M05	-1.887	-1.887	-1.882	-6.936	-6.937	-6.930	5.221	4.962	4.962
2020M06	-3.037	-3.034	-3.123	-4.073	-4.061	-4.343	3.425	3.312	3.170
2020M07	-2.934	-2.933	-3.173	-1.558	-1.575	-1.913	3.607	3.471	3.413
2020M08	-3.323	-3.352	-3.304	-0.920	-0.975	-0.811	3.716	3.563	3.604
2020M09	-3.166	-3.186	-3.105	-0.311	-0.322	-0.157	3.905	3.762	3.770
2020M10	-2.772	-2.754	-2.749	0.205	0.242	0.280	3.986	3.836	3.838

Table 14. Percentage Deviation of Sectoral Output from Baseline: Service Industries (%)

	(a) Accommodations			(b) Eating and Drinking Services			(c) Amusement Services		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
2020M05	-21.144	-21.146	-21.135	-21.091	-21.092	-21.084	-14.791	-14.791	-14.792
2020M06	-12.965	-12.775	-14.449	-10.760	-10.680	-11.503	-9.342	-9.261	-10.211
2020M07	-12.137	-12.269	-12.084	-7.455	-7.523	-7.355	-8.418	-8.497	-8.336
2020M08	-9.927	-10.128	-9.527	-4.842	-4.925	-4.600	-6.808	-6.913	-6.537
2020M09	-7.147	-7.024	-6.971	-2.775	-2.701	-2.683	-5.024	-4.943	-4.907
2020M10	-4.985	-4.985	-4.859	-1.490	-1.488	-1.435	-3.648	-3.646	-3.570

Table 15. Percentage Deviation of Private Consumption from Baseline (%)

	(a) Non-Durable Goods (Department Stores)			(b) Non-Durable Goods (Super Markets)			(c) Durable Goods (Cars)		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
2020M05	-32.953	-32.953	-33.167	0.633	0.633	0.490	0.633	0.633	0.490
2020M06	-16.289	-16.309	-16.452	0.550	0.539	0.527	0.550	0.539	0.527
2020M07	-7.715	-7.758	-7.771	0.116	0.100	0.128	0.116	0.100	0.128
2020M08	-3.567	-3.572	-3.597	0.028	0.036	0.027	0.028	0.036	0.027
2020M09	-1.652	-1.658	-1.672	0.015	0.014	0.013	0.015	0.014	0.013
2020M10	-0.705	-0.711	-0.721	0.009	0.007	0.005	0.009	0.007	0.005

Table 16. Working Time by Sector (%)

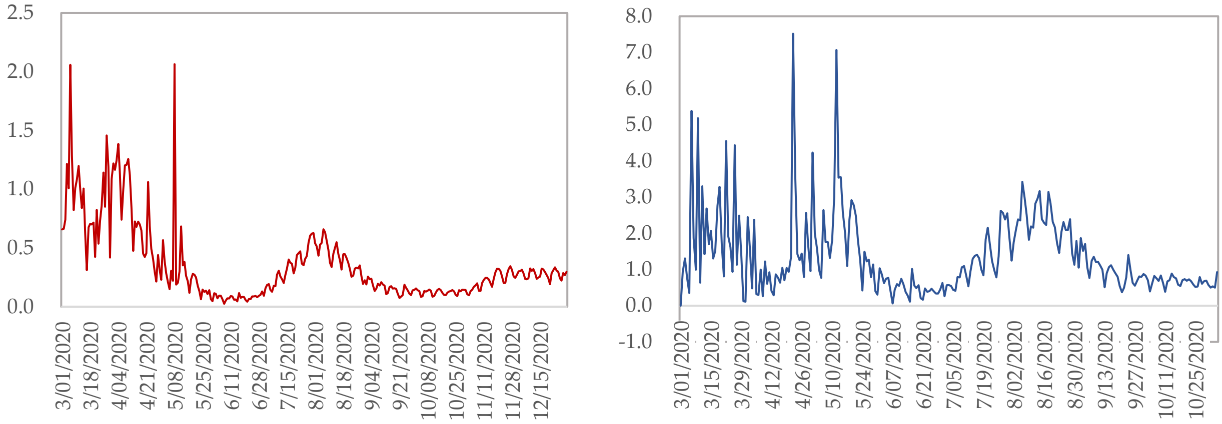
	(a) Information and Communications services			(b) Accommodations			(c) Eating and Drinking Services		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
2020M05	0.028	0.028	0.028	-5.607	-5.607	-5.592	-12.080	-12.080	-12.077
2020M06	0.151	0.151	0.101	-3.368	-3.367	-3.577	-8.006	-8.006	-8.078
2020M07	-0.065	-0.068	-0.017	-2.506	-2.521	-2.614	-5.457	-5.461	-5.481
2020M08	-0.028	-0.070	0.012	-1.891	-1.968	-1.853	-3.718	-3.760	-3.691
2020M09	0.017	0.099	-0.025	-1.368	-1.299	-1.367	-2.505	-2.461	-2.517
2020M10	0.052	0.010	0.052	-0.946	-0.959	-0.928	-1.658	-1.664	-1.661

Table 17. Percentage Deviation of Wage by Sector (%)

	(a) Manufacturing (Average)			(b) Services (Average)			(c) Retail Trades		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
2020M05	-1.187	-1.187	-1.185	-0.910	-0.910	-0.909	1.847	1.847	1.832
2020M06	-1.143	-1.143	-1.184	-0.716	-0.715	-0.775	1.464	1.463	1.465
2020M07	-1.150	-1.152	-1.145	-0.780	-0.784	-0.743	1.191	1.178	1.204
2020M08	-1.041	-1.065	-1.060	-0.690	-0.732	-0.699	0.960	0.974	0.957
2020M09	-1.298	-1.259	-1.306	-1.342	-1.265	-1.373	0.673	0.672	0.671
2020M10	-1.160	-1.213	-1.121	-1.201	-1.288	-1.152	0.494	0.493	0.492

Figure 1. The estimated Parameters β_t and γ_t

(i) The effective transmission rate β_t (ii) The remove and recovery rate γ_t



Note: β_t and γ_t are normalized by values of April 7 in 2020, which is the day that the Japanese government declared a state of emergency.

Figure 2. Increasing or Decreasing Index of the Infection: $\beta S_t - \gamma_t$

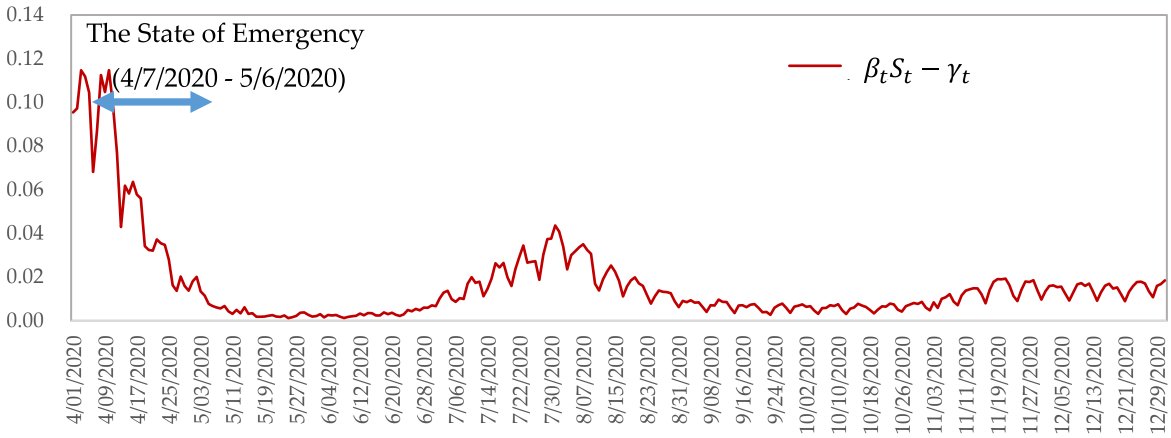


Figure 3. Changes in the Duration of Time Spent at Home