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Asset pricing during pandemic lockdown

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ABSTRACT

This paper examines the implications of lockdown policies during early stages of pandemics for asset prices. We build a simple susceptible-infected-recovered model with microeconomic foundations, which allows us to obtain qualitative results with economic implications. In our model, lockdown policies reduce (i) labour income by decreasing working hours and (ii) precautionary savings by decreasing susceptible agents' probability of getting infected in the future. We qualitatively show that strengthening lockdown measures negatively impacts asset prices at the time of implementation. Our empirical analysis using data from advanced countries supports this finding. Depending on parameter values, our numerical analysis displays a V-shaped recovery of asset prices and an L-shaped recession of consumption. The rapid recovery of asset prices occurs only if the lockdown policies are insufficiently stringent to reduce the number of new periodic cases. This finding implies the possibility that lenient lockdowns have contributed to rapid stock market recovery at the beginning of the COVID-19 pandemic.

1. Introduction

The COVID-19 pandemic has been plunging the global economy into a severe recession.[3] By contrast, stock markets have been recovering amidst strict lockdown restrictions. (see Fig. 1). To decipher the causes of the divergence between the two markets, this paper develops a framework to provide primary economic implications of lockdown policies for asset prices.

We consider a consumption-based economy á la Lucas (1978) combined with Kermack and McKendrick' (1927) s susceptible-infected-recovered (SIR) model. The population is divided into susceptible, infected and recovered agents. Susceptible agents receive a time endowment, which is inelastically supplied to the labour market. The length of their working hours affects their probability of getting infected in the next period. Recovered agents are immune to the virus and inelastically supply their time endowments. To eliminate transmission of the virus, the government (or social planner) can reduce a fraction of time endowments. We refer to this government restriction as lockdown.

Our qualitative analysis shows that the impacts of lockdown restrictions on asset prices are twofold. First, lockdowns decrease labour income (and hence consumption) at the period of its implementation. If a lockdown is immediately implemented at the current period, then it decreases current consumption, asset accumulation and asset prices. In contrast, a future lockdown allows agents to

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[3] According to the World Bank forecasts, for instance, economic activities of the advanced and developing economies in 2020 are expected to decrease by 7% and 2.5%, respectively.

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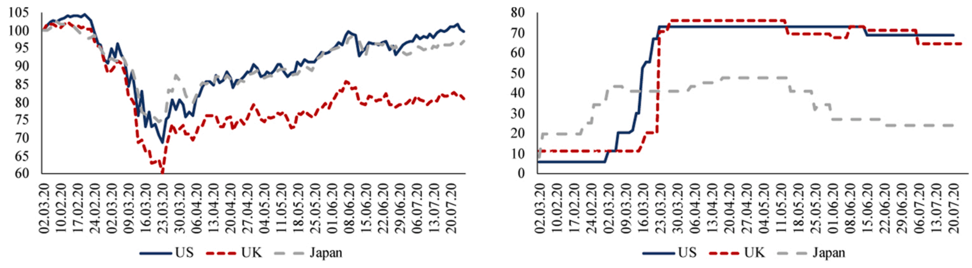


Stock Price Stringency of Lockdown

Fig. 1. Stock Price and Stringency of Lockdowns. *Note*: The data on stock prices are obtained from the MSCI World Index. Figure (b) plots the government stringency index, provided by the Oxford COVID-19 Government Response Tracker (OxCGRT), which ranges from 0 to 100, recording wide range of government's responses to the pandemic.

expect a reduction in their future labour income. Thus a future lockdown increases asset accumulation and asset prices at the period of implementation. Second, lockdowns decrease susceptible agents' future risks of infection and their precautionary saving motives toward the risk of losing future labour income. This effect decreases asset demand and prices at the period of implementation.

Our numerical experiments examine the impact of different lockdown schedules on asset price dynamics. We show that a stringent lockdown schedule negatively impacts stock prices. The finding is consistent with our empirical analysis of data from advanced countries during the COVID-19 pandemic. We also show that an L-shaped consumption trajectory associated with a V-shaped asset price trajectory across periods. The V-shaped recovery of asset markets happens only if the number of new cases increases due to the insufficiently strict lockdowns. In cases where lockdowns are sufficiently strict and can reduce new periodic cases, by contrast, introducing lockdowns only flattens the declining asset price slope. The finding implies the possibility that lenient lockdowns have contributed to the stock market recovery at the beginning of the COVID-19 pandemic.

We also study the effects of an exogenous increase in cash handouts to agents on asset prices. Unlike lockdowns, cash handouts do not influence the spread of infection and only increase agents' disposable income at the period of lockdown. Thus cash handouts enhance current asset prices if they are implemented at the current period. By contrast, future cash transfers negatively affect present asset prices by dis-incentivising asset accumulation.

Several studies have theoretically investigated asset markets during pandemics. Rietz (1988), Barro (2006), and Barro (2009) have studied the effects of existing risk of rare disasters on asset markets. Using a model of endogenous risk intolerance, Caballero and Simsek (2020) analyses the impact of central banks' large-scale asset purchases on asset markets during a pandemic.

The most closely related previous studies are Toda (2020) and Detemple (2020), both of which embed SIR models into assets pricing models. Toda (2020) numerically studies asset prices in an SIR model by using the US data during the COVID-19 pandemic; the results shows that a negative relationship between stock prices and the infected population. In contrast to Toda (2020), we provide the qualitative properties of the effect of lockdowns on asset prices, which facilitate the understanding of economic implications of lockdowns. Using a similar epidemiological model, Detemple (2020) studies asset markets during a pandemic and shows that stock prices and interest rates behave cyclically during an outbreak. In contrast to Detemple (2020), we provide empirical evidence that supports our theoretical findings by using the data at the beginning of the COVID-19 pandemic. In addition to this contribution, we compares the effect of cash handout policies on asset prices and that of lockdown policies, which, to the best of our knowledge, has not been examined in the existing literature.

This paper is also related with the growing literature on empirical studies of financial markets during the COVID-19 pandemic. The list of the literature includes Al-Awadhi et al. (2020), Akhtaruzzaman et al. (2020), Ashraf (2020), Baker et al. (2020), Giglio et al. (2020), Pagano et al. (2020), Sharif et al. (2020) and Zhang et al. (2020). Notably, Baker et al. (2020) argue that stock market volatility during the COVID-19 pandemic is largely the consequence of governments' responses—such as lockdowns, business shutdown, and direct cash transfers.

Finally, this paper contributes to the emerging debate on the macroeconomic impacts of a pandemic. Using macroeconomic-SIR models, numerous studies have investigated the economic consequences of pandemic shocks and their implications for welfare and policymaking. An incomplete list of those studies includes Acemoglu et al. (2020), Albanesi et al. (2020), Alon et al. (2020), Alvarez et al. (2020), Atkeson (2020), Bodenstein et al. (2020), Eichenbaum et al. (2020), Ferguson et al. (2020), Fernández-Villaverde and Jones (2020), Glover et al. (2020), Jones et al. (2020), Kaplan et al. (2020), Krueger et al. (2020) and Toxvaerd (2020).

The rest of the paper is organised as follows. Section 2 shows how our model illustrates lockdown and economic activities during a pandemic. Section 3 qualitatively and qualitatively studies how pandemic policies affect the asset prices, provides supporting evidence on our theoretical predictions, and discuss intuitions. Lately, Section 4 concludes the paper by discussing the limitations of our analysis.

2. Model

This section illustrates our modelling of a pandemic and describes the individual economic behaviours and conditions satisfied in equilibrium.

2.1. Pandemic and lockdown

We consider a version of the SIR epidemic model where economic behaviour and public policies affect the spread of a disease. Times are discrete: $t = 0, 1, 2, \ldots$. In each period t, total population N_t is divided into three groups, namely, susceptible S_t, infected I_t, and recovered agents R_t. Hence it holds that:

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

where $N_t = 1$ is assumed for all t. Susceptible agents are those who have never been infected and have not had immunity to the virus. Infected agents are those who have been infected before and not recovered at the present period. They will recover in the next period with probability $\gamma > 0$ and will continuously be ill in the next period with probability $1 - \gamma$. When the infected agents meet the susceptible agents, they transmit the virus at a rate of $\delta > 0$. Recovered agents are those who had been previously infected but have recovered from the disease. We suppose they are immune to the virus. We specify the law of motion of S_t, I_t and R_t are given by the following respectively:

$$S_{t+1} = (1 - \delta L_t^S I_t) S_t, \tag{2}$$

$$I_{t+1} = (1 + \delta S_t L_t^S - \gamma) I_t, \tag{3}$$

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

L_t^S captures susceptible agents' degree of participation in labour activities compared with the days before the outbreak. If $L_t^S = 1$, then people work similarly to before the outbreak, whereas if $L_t^S = 0$, then they do not work at all. Note that Eqs. (2)–(4) coincide with the standard SIR model if $L_t^S = 1$ for all t. Throughout the paper, we suppose that $S_1, I_1 > 0$ and L_t^S is an exogenous working time endowment that depends on the stringency of the lockdown policy at the period.

We assume that lockdowns eliminate the transmission of the virus by reducing the agents' working hours.[4] Let $\epsilon_t \in [0, 1]$ represent the stringency of lockdown at t, and time endowments are given by:

$$L_t^i = \begin{cases} 1 - \epsilon_t & \text{if } i \in \{S, R\}, \\ 0 & \text{otherwise.} \end{cases} \tag{5}$$

Here lockdowns are supposed to reduce the transmissions of infections by decreasing agents' working hours. Note that infected agents do not receive any time endowment irrespective of stringency of the lockdown.[5] The next property shows a necessary condition of lockdowns to decrease the number of cases in the next period.

Proposition 1. *The number of infected agents at $t+1$ decreases if the lockdown at t satisfies:*

(6)$\epsilon_t > \underline{\epsilon_t}(S_t|\delta,\gamma)$, where $\underline{\epsilon_t}(S_t|\delta,\gamma) := 1 - \frac{\gamma}{\delta S_t}$. A higher value of $\underline{\epsilon_t}(S_t|\delta,\gamma)$ implies that a stricter lockdown is required to reduce the number of infected agents, and vice versa. The value of $\underline{\epsilon_t}(S_t|\delta,\gamma)$ is higher in an economy with (i) a small γ, implying high-quality medical care, (ii) a large δ, implying high public hygiene, and (iii) a large S_t, implying a large population susceptible individuals who may get infected in the future. Note that for all S_t, δ and γ, we have $\underline{\epsilon_t}(S_t|\delta,\gamma) < 1$. This condition implies that the number of new cases can be decreased without imposing complete business shutdown (i.e., $\epsilon_t = 1$).

2.2. Economy

The economy is based on Lucas (1978). Each period t there are k_t of identical infinitely-lived trees, which are the only assets existing in the economy. Each tree generates dividend d_t that cannot be stored. We suppose that each tree's dividend stream is i.i.d., and given by:

$$d_t = \begin{cases} d^H & w.p.\ \ \pi \\ d^L & w.p.\ \ 1 - \pi \end{cases} \tag{7}$$

where $\pi \in [0, 1]$ and $d^H > d^L$. Agents in state $\theta_t \in \{S, I, R\}$ at t face the following budget constraint:

$$c_t(\theta_t) + p_t k_{t+1}(\theta_t) = w_t L_t(\theta_t) + (p_t + d_t) k_t(\theta_{t-1}) + b_t. \tag{8}$$

where w_t is the wage rate, c_t is the amount of consumption, b_t is the monetary endowment and p_t is the market price of a tree.

[4] Alvarez et al. (2020) study a model with a similar specification on the lockdown policies.

[5] Whether recovered agents become immune to COVID-19 is under discussion. However this assumption does not affect the results under Assumption 1. Since the number of recovered agents is small in the early stages of pandemics, recovered agents' actions do not impact the aggregate economy.

Susceptible and infected agents are uncertain about their future states. In contrast, recovered agents are certain about their future state (they know they are immune to the virus). Let $q_{t+1}^{\theta_{t+1}|\theta_t}$ denote the probability of an agent in state θ_t at t will become in state θ_{t+1} at $t+1$. Then Eqs. (2)–(4) imply $q_{t+1}^{S|S} = 1-\delta L_t I_t$, $q_{t+1}^{I|S} = \delta L_t I_t$, $q_{t+1}^{R|S} = 0$, $q_{t+1}^{S|I} = 0$, $q_{t+1}^{I|I} = 1-\gamma$, $q_{t+1}^{R|I} = \gamma$, $q_{t+1}^{S|R} = 0$ and $q_{t+1}^{I|R} = 0$.

Agents at t evaluate the intertemporal utility as follows:

$$\mathbb{E}_t\left[\sum_{\omega=0}^{\infty}\beta^{\omega}[u(c_{t+\omega}(\theta_{t+\omega}))]\right] \tag{9}$$

where $\beta \in (0,1)$ is their discount factor and $\mathbb{E}_t$ is the expectation operator at t. The instant utility u is assumed to be strictly increasing, concave and twice continuously differentiable.

Each agent i maximises the intertemporal utility (9) subject to the budget constraint (8). By arranging the first-order conditions, we obtain the following Euler equation:

$$u'(c_t(\theta_t)) = \beta\mathbb{E}_t\left[u'(c_{t+1}(\theta_{t+1}))\left(\frac{p_{t+1}+d_{t+1}}{p_t}\right)\right] \tag{10}$$

In equilibrium, aggregate dividend is all consumed and asset market clears. Thus we have $S_t c_t^S + I_t c_t^I + R_t c_t^R = d_t K_t$, and $S_t k_t^S + I_t k_t^I + R_t k_t^R = K_t$.

3. Analysis

This section discusses the results and the implications of our analyses.

Assumption 1. $S_t \approx N_t$

This assumption can be interpreted as the pandemic is in an early stage when only a marginal fraction of population is infected. We consider this assumption as reasonable to analyse the early impacts of the COVID-19 pandemic lockdowns when the cumulative confirmed cases are relatively small–for instance, as of June 10, 2020, the number of cumulative confirmed cases divided by the total population is 0.0006% in China, 0.2219% in Germany, 0.3842% in Italy, 0.0138% in Japan, 0.0230% in South Korea, 0.5091% in Spain, 0.5803% in the US and 0.4076 in the UK.[6]

Proposition 2. *Suppose Assumption* 1. *Then*

(11)$p_t \approx \widetilde{p}_t = \frac{1}{u'(c_t^S)}\mathbb{E}_t[m]$*where*

$$m := \beta\left(\sum_{\theta_{t+1}\in\{S,I\}} q_{t+1}^{\theta_{t+1}|S} u'(c_{t+1}(\theta_{t+1}))\right)d_{t+1} + \beta^2\left(\sum_{\theta_{t+1}\in\{S,I\}} q_{t+1}^{\theta_{t+1}|S} \sum_{\theta_{t+2}\in\{S,I,R\}} q_{t+2}^{\theta_{t+2}|\theta_{t+1}} u'(c_{t+2}(\theta_{t+2}))\right)d_{t+2} + \cdots$$

The asset price at t is determined by the present discounted value of the stream of future endowments. The probabilities and consumption are influenced by the policies implemented by the government. The next section studies the effect of lockdown on the asset price at t.

3.1. Qualitative analysis and supporting evidence

3.1.1. Qualitative analysis

Corollary 1. (*(Impact of lockdown on asset prices)*) *Suppose* ϵ_t *satisfies the condition* (6) *for all* t. *Then*

(12)$$\frac{d\widetilde{p}_t}{d\epsilon_t} = \underbrace{\overbrace{\frac{d\widetilde{p}_t}{dc_t^S}}^{+}\overbrace{\frac{dc_t^S}{d\epsilon_t}}^{-}\overbrace{\mathbb{E}_t[m]}^{+}}_{-} + \underbrace{\overbrace{\frac{1}{u'(c_t^S)}}^{+}\overbrace{\mathbb{E}_t\left[\frac{dm}{d\epsilon_t}\right]}^{-}}_{-} < 0$$

(13)$$\frac{d\widetilde{p}_t}{d\epsilon_{t+\omega}} = \underbrace{\overbrace{\frac{d\widetilde{p}_t}{dc_{t+\omega}^S}}^{-}\overbrace{\frac{dc_{t+\omega}^S}{d\epsilon_{t+\omega}}}^{-}\overbrace{\mathbb{E}_t[m]}^{+}}_{+} + \underbrace{\overbrace{\frac{1}{u'(c_t^S)}}^{+}\overbrace{\mathbb{E}_t\left[\frac{dm}{d\epsilon_{t+\omega}}\right]}^{-}}_{-} \gtreqless 0, \quad \forall\omega\in{}_{+}$$

Proof. $u'(c_t) > 0$ implies $\frac{d\widetilde{p}_t}{dc_t} > 0$ and $\frac{d\widetilde{p}_{t+s}}{dc_{t+s}} < 0$ for all $s \in {}_{+}$. Since $\frac{dc_t^S}{d\epsilon_t} = -w < 0$, we have $\frac{d\widetilde{p}_t}{dc_t^S}\frac{dc_t^S}{d\epsilon_t} < 0$ and $\frac{d\widetilde{p}_t}{dc_{t+s}^S}\frac{dc_{t+s}^S}{d\epsilon_{t+s}} > 0$ for all $s \in {}_{+}$. Note that

$$\frac{dm}{d\epsilon_t} = \beta\left(\sum_{\theta_{t+1}\in\{S,I\}}\frac{dq_{t+1}^{\theta_{t+1}|S}}{d\epsilon_t}u'(c_{t+1}^j)\right)d_{t+1} + \beta^2\left(q_{t+1}^{S|S}\sum_{\theta_{t+2}\in\{S,I\}}\frac{dq_{t+2}^{\theta_{t+2}|S}}{d\epsilon_t}u'(c_{t+2}^j)\right)d_{t+2} + \cdots.$$

[6] The data are obtained from Our World in Data, whose original source is published by the European CDC.

By the definitions of $q^{S|S}_{t+1}$, $q^{I|S}_{t+1}$ and $L_t = 1 - \epsilon_t$, we have $\frac{\mathrm{d}q^{S|S}_{t+1}}{d\epsilon_t} = \delta I_{t+1} > 0$ and $\frac{\mathrm{d}q^{I|S}_{t+1}}{d\epsilon_t} = -\delta I_{t+\omega} < 0$. For all $\omega > 1$, if condition (6) is satisfied, then we have $\frac{\mathrm{dI}_{t+\omega-1}}{d\epsilon_t} < 0$. Hence by the definitions of $q^{S|S}_{t+\omega}$ and $q^{I|S}_{t+\omega}$, we have

$$\frac{\mathrm{d}q^{S|S}_{t+\omega}}{d\epsilon_t} = -\delta\left(\frac{\mathrm{dI}_{t+\omega-1}}{d\epsilon_t}L^S_{t+\omega-1}\right)\Big\rangle 0,$$

$$\frac{\mathrm{d}q^{I|S}_{t+\omega}}{d\epsilon_t} = \delta\left(\frac{\mathrm{dI}_{t+\omega-1}}{d\epsilon_t}L^S_{t+\omega-1}\right)\Big\langle 0,$$

$$\frac{\mathrm{d}q^{S|S}_{t+\omega}}{d\epsilon_t} = -\delta\left(\frac{\mathrm{dI}_{t+\omega-1}}{d\epsilon_t}L^S_{t+\omega-1}\right)\Big\rangle 0,$$

$$\frac{\mathrm{d}q^{I|S}_{t+\omega}}{d\epsilon_t} = \delta\left(\frac{\mathrm{dI}_{t+\omega-1}}{d\epsilon_t}L^S_{t+\omega-1}\right)\Big\langle 0,$$

for all $\omega > 1$. Since $u'(c_t) > 0$, $u''(c_t) < 0$, and $c^S_{t+\omega} > c^I_{t+\omega}$ imply $u'(c^S_{t+\omega}) - u'(c^I_{t+\omega}) < 0$, we have

$$\sum_{\theta_{t+\omega}\in S,I} u'(c^S_{t+\omega})\frac{\mathrm{d}q^{\theta_{t+\omega}|S}_{t+\omega}}{d\epsilon_t} = \frac{\mathrm{d}q^{S|S}_{t+\omega}}{d\epsilon_t}\left(u'(c^S_{t+\omega}) - u'(c^I_{t+\omega})\right)\big\langle 0$$

for all t and $\omega \geq 0$. Hence $\frac{d\Delta}{d\epsilon_t} < 0$ and the results immediately follow.□

The results show how different lockdown schedule causes different impacts on asset prices. Strengthening current-period lockdown decreases asset price at the time, whereas while the impacts of strengthening future-periods lockdowns are unclear. An increase in lockdown stringency affects the asset price at t, regardless of the timing of implementation, by decreasing (i) consumption and (ii) future probabilities of getting the virus.

The first terms in the right-hand-sides of Eqs. (12) and (13) represent the economic impacts of strengthening lockdown measures on consumption. A stricter lockdown decreases working hours, asset demand and its price at the period of implementation. If the government commits to a stricter lockdown in the future, then individuals expect a reduction in future labour endowment. To prepare for that, individuals demand additional assets. This behaviour hikes present asset prices.

The second terms in the right-hand-sides of Eqs. (12) and (13) illustrate the effects of strengthening lockdown measures on the spread of infection. A stricter lockdown decreases susceptible agents' future risks of infection and precautionary saving motives towards the risk of losing working hours. As a result, asset demand and its present prices decrease.

These analyses raise the following questions. First an introduction of lockdown induces individuals to expect that it will continue for several periods. This situation means that the effects of Eqs. (12) and (13) arise at the same time and present asset prices depend on the entire lockdown schedule. In Section 3.2, we numerically deal with this issue by supposing that individuals believe a lockdown schedule $\{\epsilon_t, \epsilon_{t+1}, \epsilon_{t+2}, \ldots\}$ at an initial period t.

Second if the condition (6) is not satisfied, then strengthening lockdown measures does not necessarily reduce the number of infected agents. For instance, consider a scenario where the government does not impose any economic activity restrictions and *herd immunity* is reached at $t = 100$ (i.e., $\epsilon_t = 0$ for all t and $q^{I|S}_{100} = 0$). Then, strengthening restrictions at period $t = 10$ may reduce new cases at $t = 11$ but may delay the date of achieving herd immunity (i.e., it holds that $q^{I|S}_{100} > 0$ and $\frac{\mathrm{d}q^{I|S}_{100}}{d\epsilon_{10}} > 0$, and the sign of (12) is not always negative). Our numerical experiments in Section 3.2 examines scenarios with $\epsilon_t < \underline{\epsilon}$ and how asset prices react to lenient lockdowns.

We now consider the effect of cash handouts to agents on the asset prices. For simplicity, we suppose b_t is an exogenous endowment and do not consider its effect on the government budget constraint.

Corollary 2. (*Effect of Cash Handouts on Asset Prices*) (14) $\frac{d\widetilde{p}_t}{\mathrm{db}_t} = \underbrace{\overbrace{\frac{d\widetilde{p}_t}{\mathrm{dc}^S_t}}^{+}\overbrace{\frac{\mathrm{dc}^S_t}{\mathrm{db}_t}}^{+}\overbrace{\mathbb{E}_t[m]}^{+}}_{+} > 0$

(15) $\frac{d\widetilde{p}_t}{\mathrm{db}_{t+\omega}} = \underbrace{\overbrace{\frac{d\widetilde{p}_t}{\mathrm{dc}^S_{t+\omega}}}^{-}\overbrace{\frac{\mathrm{dc}^S_{t+\omega}}{\mathrm{db}_{t+\omega}}}^{+}\overbrace{\mathbb{E}_t[m]}^{+}}_{-} < 0, \quad \forall\omega \in \mathbb{N}_+.$

$$\frac{d\widetilde{p}_t}{\mathrm{db}_t} = \underbrace{\overbrace{\frac{d\widetilde{p}_t}{\mathrm{dc}^S_t}}^{+}\overbrace{\frac{\mathrm{dc}^S_t}{\mathrm{db}_t}}^{+}\overbrace{\mathbb{E}_t[m]}^{+}}_{+} > 0 \tag{14}$$

$$\frac{d\widetilde{p}_t}{\mathrm{db}_{t+\omega}} = \underbrace{\overbrace{\frac{d\widetilde{p}_t}{\mathrm{dc}^S_{t+\omega}}}^{-}\overbrace{\frac{\mathrm{dc}^S_{t+\omega}}{\mathrm{db}_{t+\omega}}}^{+}\overbrace{\mathbb{E}_t[m]}^{+}}_{-} < 0, \quad \forall\omega \in \mathbb{N}_+. \tag{15}$$

Table 1
Summary of data.

Panel A: Summary statistics

	N	Mean	Std. dev	Min	Max
ΔStringency index	295	2.944	11.262	− 47.220	50.000
ΔEconomic support index	57	28.289	25.170	− 25.000	100.000
Return	2643	0.000	0.027	− 0.186	0.130

Panel B: Correlation matrix

	ΔStringency index	ΔEconomic	Return
ΔStringency index	1.000	0.518	− 0.295
ΔEconomic support index	0.518	1.000	− 0.028
Return	− 0.295	− 0.028	1.000

Notes: The indexes of stock returns are obtained from the MSCI World Index. “stringency index” and “economic support index” are obtained from OxCGRT.

Table 2
Correlation between stock return and variable changes.

Countries	ΔGovernment response index	ΔStringency index	ΔNew cases per million
Australia	0.133	0.014	0.013
Austria	− 0.442	− 0.491	0.092
Belgium	− 0.361	− 0.384	0.075
Canada	− 0.572	− 0.718	0.186
Denmark	− 0.025	0.002	− 0.039
Finland	− 0.411	− 0.465	0.178
France	− 0.338	0.047	0.020
Germany	− 0.105	− 0.124	0.147
Ireland	− 0.328	− 0.372	0.096
Israel	− 0.382	− 0.372	0.077
Italy	− 0.215	− 0.268	0.029
Japan	− 0.154	− 0.075	0.071
Netherlands	− 0.468	− 0.617	0.111
New Zealand	− 0.143	− 0.121	0.141
Norway	− 0.182	− 0.326	0.060
Portugal	− 0.405	− 0.327	0.157
Singapore	− 0.026	− 0.027	0.084
Spain	− 0.391	− 0.459	0.085
Sweden	− 0.109	− 0.239	0.065
Switzerland	0.098	0.084	0.113
United Kingdom	− 0.021	− 0.533	0.122
United States	− 0.620	− 0.593	0.135

Note: Data on the number of new cases (new cases Per million) are obtained from Our World in Data, whose original source is published by the European CDC.

Proof. Note that $\frac{\mathrm{dc}_t}{\mathrm{db}_t} = 1$ for all $t \in \mathbb{N}_+$. $\frac{d\widetilde{p}_t}{\mathrm{dc}_t} > 0$ implies the first result. $\frac{d\widetilde{p}_t}{\mathrm{dc}_{t+s}} < 0\ \forall s \in \mathbb{N}_+$ implies the second result. □

In contrast to lockdowns, cash handouts increase the disposable income and do not affect the spread of infection. An increase in monetary transfer only enhances asset demand and prices at the period. Expected future cash handouts decrease current asset prices by dis-incentivising asset accumulation.

3.1.2. Supporting evidence

Using indexes from OxCGRT, this section tests our theoretical prediction that strengthening lockdown measures and decreasing monetary transfers negatively affect asset prices at the time of implementation. Table 1 summarise the data.

Table 2 shows the correlation between each developed country’s stock return index and the changes in government responses. “Government response index” measures overall government response, including lockdown, testing policy, and economic support. “Stringency index” only records the strictness of “lockdown style” policies. Δ represents change in the variable from the day before.

Most countries have negative correlations between stock returns and an increase in the stringency of restrictions from the day

Table 3
Result of regression.

	Model 1	Model 2	Model 3
ΔStringency index	− 0.0006***		− 0.0013**
	(0.0002)		(0.0004)
ΔEconomic support index		0.0001	0.0002**
		(0.0001)	(0.0001)
R^2	0.8462	0.8662	0.9658
Adj. R^2	0.7681	0.7118	0.8633
Num. Obs.	295	57	21
RMSE	0.0193	0.0251	0.0206

Note: Robust standard errors in parentheses ** and *** represent significance at 5% and 1%, respectively.

Table 4
Parameter values.

Economic parameters	SIR parameters
$\delta = 0.999,\ \rho = 2,\ \pi = 0.7,$ $d^H = 0.01,\ d^L = 0.001$	$\beta = 0.20,\ \gamma = 1/18,$ $I_0 = 0.0002,\ S_0 = 1 - I_0$

before. The finding implies that the negative impacts of increasing the stringency of lockdowns (Eq. (12)), surpassed the positive impacts on implementing economic supports, such as direct cash handouts (Eq. (14)). Stock returns and the change in the number of new cases are also positively correlated. This is consistent with our theoretical prediction that an increase in the number of new cases increases the asset prices by incentivising susceptible agents' precautionary saving motives.

We now estimate the effects of strengthening lockdowns and economic supports on market returns using the following model:

$$r_t^i = \lambda_1 \Delta \text{Stringency Index}_t^i + \lambda_2 \Delta \text{Economic Support Index}_t^i + \eta_t + u_t^i \tag{16}$$

where r_t^i represents the market returns of country i at time t, $\Delta\text{Stringency Index}_t^i$ represents the difference of the OxCGRT "stringency index" at country i from time $t-1$ to t, and $\text{Economic Support Index}_t^i$ represents the difference of the OxCGRT "economic support index" at country i from time $t-1$ to t.[7]

The results are reported in Table 3. The coefficient on $\Delta\text{Stringency Index}_t^i$ is negative and strongly significant in Model 1 and Model 3. The result means that increasing the lockdown stringency decreases stock returns at the time. The result is consistent with our theoretical prediction (12). The coefficient on $\Delta\text{Transfer}_t^i$ is positive and strongly significant in Model 3, meaning that strengthening economic support hikes stock returns at the time. The result is consistent with our theoretical prediction (14).

3.2. Numerical experiments

We now demonstrate quantitative studies where a lockdown schedule $\{\epsilon_t, \epsilon_{t+1}, \epsilon_{t+2}, \ldots\}$ is committed at the beginning of period t. Throughout our numerical analysis, we suppose instant utility from consumption is constant relative risk aversion (CRRA):

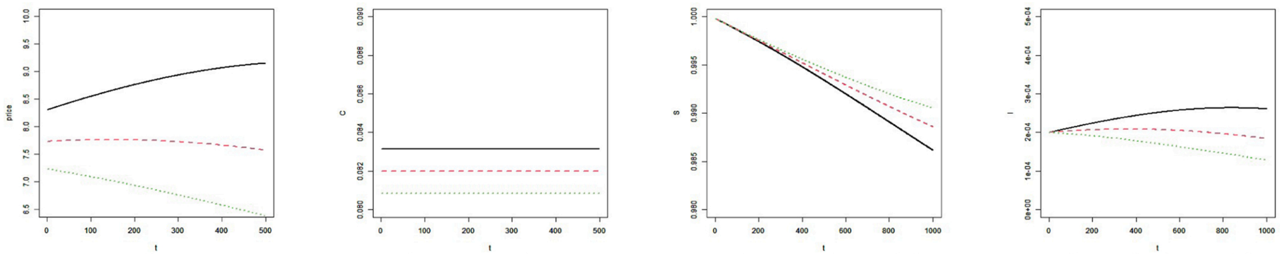
$$u(c_t) = \frac{c_t^{1-\sigma}}{1-\sigma}. \tag{17}$$

Table 4 presents the parameter values for our computations. We assume that the annual discount rate is 4%, which means that the daily discount factor is: $\delta = \exp(- - - 0.04/365) \approx 0.999$. The infection rate is supposed at $\beta = 0.20$, meaning that the daily increase in active cases would be 20 percent without any lockdown. The parameter γ, the probability that an infected agent recovers in a day, is set to $\gamma = 1/18$, which means that the expected duration of illness is 18 days as Atkeson (2020).

Figs. 2 demonstrates the outcomes of our benchmark cases, where lockdown is constant in every period, that is, $\epsilon_t = \epsilon \in \{0.719, 0.721, 0.723\}$ for all t. In the case of $\epsilon = 0.719$ (dotted lines), the committed lockdown schedule sufficiently decreases the population of infected agents across periods (i.e., condition (6) is satisfied for all t). In the case of $\epsilon = 0.721$ (slashed lines), the number of new cases initially increases but decreases later. This trajectory is caused by gradual reductions in S_t and $\underline{\epsilon_t}(S_t|\delta,\gamma)$, which let $\epsilon = 0.721$ to satisfy condition (6). In the case of $\epsilon = 0.723$ (solid lines), lockdowns are lenient and the number of new cases increases across periods (condition (6) is not satisfied for all t).

Asset prices are higher in the cases of lenient lockdowns where susceptible agents face a high probability of infections and have high

[7] The market returns are calculated using the data from the MSCI Country Indexes.



Asset Price | Consumption | Population of S_t | Population of I_t

Fig. 2. Constant Lockdowns. Constant Lockdowns (The solid-lines suppose $\epsilon = 0.719$, the slashed-lines suppose $\epsilon = 0.721$, and the dotted-lines suppose $\epsilon = 0.723$.)

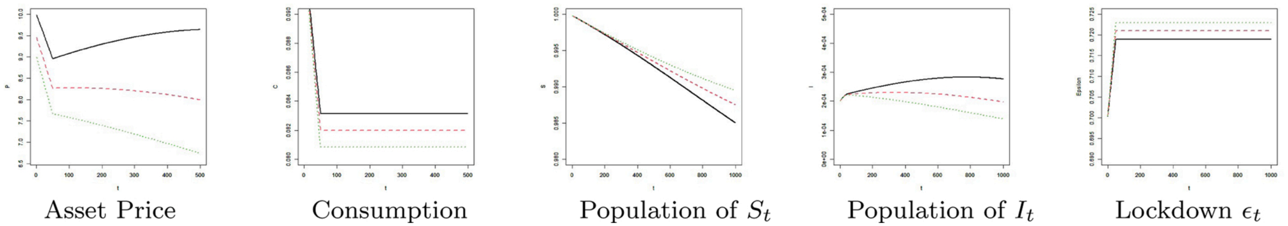


Fig. 3. Time-variant Lockdown. Time-variant Lockdown (ϵ_t linearly increases from $\varepsilon_0 = 0.7$ to $\epsilon_{50} = \epsilon$, and $\epsilon_t = \epsilon$ for all $t \geq 51$. The solid lines suppose $\epsilon = 0.719$; the slashed lines suppose $\epsilon = 0.721$; and the dotted lines suppose $\epsilon = 0.723$.)

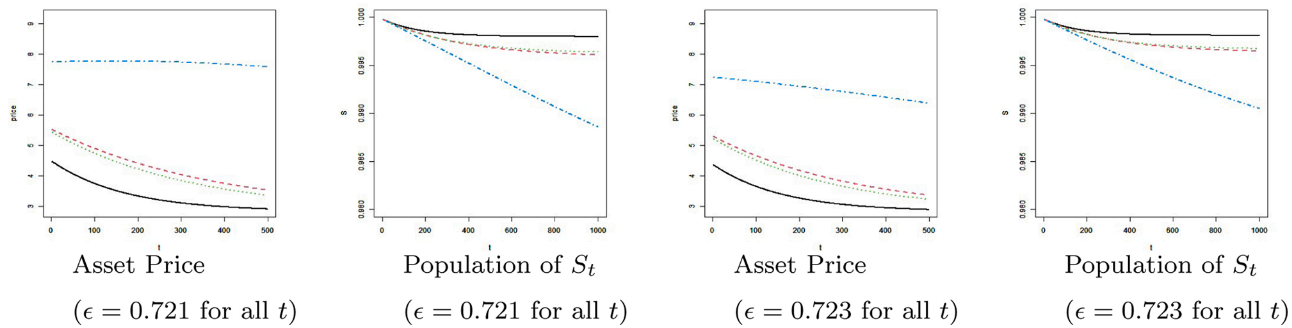


Fig. A.4. Impacts of δ and γ. *Note*: The solid lines suppose $\{\delta = 0.19, \gamma = 1/17\}$; the dashed lines suppose $\{\delta = 0.19, \gamma = 1/18\}$; the dotted line suppose $\{\delta = 0.20, \gamma = 1/17\}$ and the dotted dashed lines suppose $\{\delta = 0.20, \gamma = 1/18\}$.

precautionary saving motives. Thus asset demand and prices are high in those cases. Moreover, asset prices increase across periods in those cases whereas they decrease in the scenarios of severe lockdowns. This behaviour is also caused by the dynamics of the number of infected agents. As new cases increase, susceptible agents have precautionary saving motives, and vice versa.

Fig. 3 supposes that lockdown stringency changes across periods. We assume that ϵ_t linearly increase from $\varepsilon_0 = 0.7$ to $\epsilon_{50} = \epsilon \in \{0.719, 0.721, 0.723\}$ and $\epsilon_t = \epsilon$ for all $t \geq 51$. Before reaching $t = 50$, prices drastically fall in each case. After period $t = 50$, asset prices rebound in the lenient case, in which (6) is not satisfied, due to the same mechanism as the lenient constant lockdown scenario in Fig. 3. As a result, the asset prices illustrate a V-shaped trajectory, whereas consumption continues to in a low value.

4. Conclusion

We conclude by discussing the limitations of our study and promising future extensions. First, Assumption 1 is inadequate to analyse scenarios where a large fraction of population has been infected. In those cases, an increase in recovered agents' population may reduce asset prices since their asset demand is not high, unlike that of susceptible agents, due to the lack of their precautionary saving motives.

Second, we have not considered the effects of increasing cash handouts on the government budget constraints. In reality, an increase in fiscal expenditure may enable the agents to anticipate future tax hikes. Its effects on economic activities depend on the fiscal resources (e.g., committing an increase in labour income tax rate in the future may incentivise present asset accumulation, whereas committing an increase in future capital income tax rate may dis-incentivise it).

Finally, we have supposed rational expectations, which may be an inadequate assumption in an unprecedented situation. If the public is supposed to be optimistic towards the effects of lockdown on infection control, then asset demand may shrink by reducing the precautionary saving motives. On the contrary, if the individuals are pessimistic, then asset demand may increase.[8]

Author statement

Yuta Saito: Conceptualization, Methodology, Formal analysis, Investigation, Writing – Original Draft, Writing – Review & Editing, Visualization, Project administration, Funding acquisition.

Jun Sakamoto: Software, Formal analysis, Investigation, Data Curation, Visualization, Project administration, Funding acquisition.

Appendix A. Sensitivity of epidemiology parameters

Since the information on COVID-19 is yet incomplete, there could be misspecification on the parameters. In Fig. A.4, we investigate the effect of changing the parameters on the virus's characteristics on our results. Fig. A.4 shows both a greater δ and a smaller γ lead to higher asset prices. In a nutshell, both effects increase the number of infected agents per period: increasing δ directly increases the probability of getting the virus; decreasing γ increases the average periods of an infected agent staying at the state. Also, the impacts of decreasing γ (increasing δ) on asset prices are greater in the cases of a higher δ (lower γ). In the severer lockdown case ($\epsilon_t = 0.723$), however, the effects of changing the SIR parameters on asset prices are relatively small compared to the results of $\epsilon_t = 0.721$. In this case, agents do not interact with each other in the first place, so changing the virus's characteristics does not greatly influence the spread of infections.

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[8] In a similar context, using investor survey data Giglio et al. (2020) found that investors who were initially pessimistic and optimistic differed in their subsequent portfolio rebalancing.

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