COVID-19 and stigma: Evolution of self-restraint behavior

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COVID-19 and stigma: Evolution of self-restraint behavior *

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Abstract

Social stigma can effectively prevent people from going out and possibly spreading COVID-19. Using the framework of replicator dynamics, this study analyzes the interaction between self-restraint behavior, infection with viruses such as COVID-19, and stigma against going out. We show that a non-legally binding policy reduces the number of people going out in the steady state. Our comparative static analysis suggests that intensifying the stigma cost does not necessarily reduce the number of players going out because of an indirect effect of from a decrease in infection risk. The social welfare analysis suggests that the level of population share of players going out in the interior equilibrium is larger than the socially optimal level without the state of emergency, and it is the same under the state of emergency.

Keywords: COVID-19, Replicator dynamics, Self-restraint behavior, Social norm, Stigma

JEL codes: D91, I12, I18

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1 Introduction

As of October 2, 2020, more than 34 million people worldwide have contracted the novel coronavirus infection (SARS-CoV-2), making it a true pandemic (WHO, 2020). Countries around the world are implementing various policies to control the spread of the disease through trial and error. Specifically, governments are implementing policies to reduce the chance of contact with the disease in order to reduce the rate of infection. The following two types of policies restrict behavior to prevent the spread of infectious diseases: legally enforceable behavioral restrictions with fines or punishments and non-legally binding behavioral restrictions based on individual self-restraint, without penalties.

Policies enacted by several European countries and the United States have implemented legally enforceable behavioral restrictions. The United States has the highest number of cases worldwide as of October 2, 2020, with 7.4 million infected and 211,000 dead (The COVID Tracking Project, 2020). New York State, which declared a state of emergency on March 7, mandated in principle, 100% telecommuting starting March 22, on the governor's order. Companies can be fined up to 10,000 US dollars if they do not follow through and cause severe physical harm to their employees. The state of public health emergency imposed in France allows the Prime Minister, with the advice of the Minister of Health, to immediately implement a series of restrictive measures applicable throughout the country, which is a legally binding policy (France 24, 2020). Individuals who go out for purposes other than those authorized by the government, such as the purchase of living essentials, are fined between 135—3,700 Euros. In Italy, where the number of COVID-19-related deaths is at 35,968 as of October 2, 2020 (COVID-19 Situazione Italia, 2020), a decree was passed on March 10, 2020, imposing a nationwide curfew, with penalties of up to 3,000 Euros for those who do not carry a "certificate" stating the place and reason they had to go out. In Spain, Prime Minister Pedro Sánchez ordered a "state of alarm," which was legally binding on March 14 (AS, 2020). Under the Spanish state of emergency, breachers were arrested or the fined between 601 and 30,000 Euros.

In contrast, some countries, such as Japan and Sweden, imposed a non-legally binding policy based on individual self-restraint, without enforcement. In Japan, the government declared a state of emergency, which is not legally binding, which significantly restrained people from going out.

(The Japan Times, 2020a; Kyodo News, 2020; Katafuchi et al., 2020). It is widely considered to have been more successful in controlling the number of infections than in other OECD countries (Lu et al., 2020; Iwasaki and Grubaugh, 2020). How many people in Japan refrain from going out under the non-binding declaration of a state of emergency? To answer this question, we consider the interaction between infection risk, stigma, and the player's decision-making. In Japan, the phenomenon of a "self-restraint police" (*Jishuku Keisatsu* in Japanese) emerged under the state of emergency. The "self-restraint police" is a colloquial term for ordinary citizens who crack down on or attack individuals or shops that do not respond to government requests to refrain from going out or doing business. They have posted expletives on the doors of restaurants open for business and scratched cars with out-of-prefecture plates (The Japan Times, 2020c,b). The self-restraint police symbolize the stigma against those who do not comply with requests for self-restraint. This suggests that even unenforceable policies can discourage people from going out, to avoid social stigma. We apply an evolutionary game to analyze self-restraint behavior in the context of infectious disease epidemics from a stigmatization perspective.

Research on stigma has evolved around social psychology (Major et al., 2018), beginning with the discussion by Goffman (1963). There are also several studies on stigma in economics, Moffitt (1983); Besley and Coate (1992); Bhargava and Manoli (2015) study welfare stigma (Lindbeck et al., 1999; Kurita et al., 2020; Itaya and Kurita, 2020), Rasmusen (1996) analyzes the stigma related to criminal record, Kim (2003) analyzes the stigma against tax evasion, and Ennis and Weinberg (2013) investigate financial stigma.

It is important to analyze stigma in terms of going-out behavior during an infectious disease epidemic, as it may play a similar role in the fear of infection. Katafuchi et al. (2020) provide both theoretical and empirical analyses of non-legally binding policies inducing self-restraint behavior. They suppose that the player going out suffers psychological costs generated from the stigma of going out and the infection risk in their theoretical model. Their theoretical analysis shows that under a declared state of emergency, players refrain from going out because of the strong psychological costs reinforced by such a non-legally binding policy. Katafuchi et al. (2020), using Google mobility data, empirically suggest that more people in Japan refrained from going outside under a declared state of emergency, even after controlling for confounding factors, such as the risk of infection, daily precipitation, and daily sunshine hours. They explain the stigma of going out under the state of emergency, as follows:

> *"In Japan, under the state of emergency, it was a social norm to refrain from going out. Public opinion was that going out under the state of emergency was anti-social behavior.In other words, people who go out under the state of emergency are stigmatized by society as having inferior ethics because they do not follow social norms."*
>
> (P. 3, Katafuchi et al. 2020)

We suppose that the psychological costs of stigma intensify under a declared state of emergency in the model. Consequently, we show that the number of people going out in the steady state under the declared state of emergency is less than the number without it.

Several empirical studies analyze the effect of Japan's non-legally enforceable emergency declarations (Kobayashi et al., 2020; Katafuchi et al., 2020; Yamamura and Tsutsui, 2020). Kobayashi et al. (2020) show that the declaration and extension of the state of emergency has achieved some success in controlling the COVID-19 pandemic. Other studies analyze the effect of a legally binding lockdown on the economy (Acemoglu et al., 2020; Alvarez et al., 2020; Eichenbaum et al., 2020; Farboodi et al., 2020; Gharehgozli et al., 2020; Holtemöller, 2020; Mandel and Veetil, 2020; Martin et al., 2020). Acemoglu et al. (2020) and Alvarez et al. (2020) discuss the optimal lockdown policy using the theoretical model. Mandel and Veetil (2020) estimate the costs of a lockdown in some sectors of the global economy using a multi-sector model.

We present an investigation of the evolutionary model, specifically, the replicator dynamics of self-restraint behavior when stigma and the risk of infection change with the number of players going out. Evolutionary game and replicator dynamics are widely studied and applied in economics Taylor and Jonker (1978); Weibull (1997); Kandori et al. (1993); Safarzyńska and Van den Bergh (2011); Cerqueti et al. (2013); Wood et al. (2016); Shi et al. (2017); Wu (2018); Yang et al. (2018); Wu (2019); Alger et al. (2020); Norman (2020); Itaya and Kurita (2020)[1]. Taylor and Jonker (1978) was the first to model replicator dynamics, which has since been applied in many fields and for various issues. For instance, Safarzyńska and Van den Bergh (2011) analyzed technological change using replicator dynamics, Cerqueti et al. (2013) and Shi et al. (2017) consider a dynamic perspective of economic interactions and social tolerance applying it, and Itaya and Kurita (2020) analyze the

[1] Safarzyńska and van den Bergh (2010) presents a very useful survey of evolutionary economic modeling.

replicator dynamics of welfare fraud and incomplete take-up welfare in welfare benefit programs.

Although the number of studies on COVID-19 is increasing, few studies consider stigma. One of the few exceptions is Katafuchi et al. (2020), as mentioned above. They analyzed the theoretical model with stigma and infection risk and empirically tested the theoretical results using mobility data. However, they consider infection risk as exogenous, and this assumption is strict. Moreover, their model defines the fixed point of the number of players going out as an equilibrium point. This means that all players are rational enough to calculate each payoff and expect the number of players going out at least in equilibrium. Finally, they analyze the static model; however, the situation in a pandemic changes drastically change over time.

This study contributes in the following ways. First, we endogenize not only stigma cost but also infection risk, and weaken the rationality that players attain equilibrium using replicator dynamics, to beyond three concerns in the previous research mentioned here. Second, we show that the state of emergency has an effect on players' self-restraint behavior in the steady state. Third, our comparative static analysis indicates that intensifying the stigma cost does not necessarily induce the reduction in the number of players going out. Fourth, the social welfare analysis indicates that the number of players going out is larger than the socially optimal level without/under the state of emergency.

This paper proceeds as follows: In Sections 2 and 3, we present the basic setting of the model and the replicator dynamics. Section 4 investigates whether the non-legally binding policy induces self-restraint behavior. Section 5 presents the results of the comparative statics. Section 6 includes the welfare analysis. Finally, Section 7 concludes.

2 The model

This study follows the basic setting of Katafuchi et al. (2020). However, our theoretical model differs from previous studies that use a static model in that it is a dynamic analysis. We consider an economy with a population of N economic agents. For simplicity, we assume N to be constant in time. There are two actions or strategy types: Going-out and Staying-home. Let $x(t)$ be the share of going-out players in the total population at time t.

Let us suppose that agents play the game represented in Table 1 after random matching. In

Table 1: Payoff Matrix

	Going	Staying home
Going	(π_{GG}, π_{GG})	(π_{GS}, π_{SG})
Staying home	(π_{SG}, π_{GS})	(π_{SS}, π_{SS})

Table 1, $\pi_{a_i a_j}$ corresponds to player i's payoff when player i's action is a_i and player j's action is a_j, where a_i, $a_j \in \{G, S\}$, G is an abbreviation for "Going out" and S is for "Staying home." Each payoff, π_{GG}, π_{GS}, π_{SG}, and π_{SS}, is set as follows:

$$\pi_{GG} = \pi_{GS} = u_{\text{out}} - \gamma(x)c - \sigma s(x), \tag{1}$$

$$\pi_{SG} = \pi_{SS} = u_{\text{home}}. \tag{2}$$

Here, x is the proportion of players going out to the total population, u_{out} is the utility from going out, u_{home} is the utility from staying home, $\gamma(x)c$ is the subjective expected cost of infection with the virus, $\gamma(x)$ is the subjective probability of infection with the virus, c is the cost of infection with the virus, $\sigma s(x)$ is the stigma cost of going out, σ is the relative size of stigma cost to infection cost, $s(x)$ is the stigma cost function. We assume that the subjective probability of infection with the virus is an increasing function with the proportion of players going out in the total population as follows:

$$\gamma(x) = \eta x, \tag{3}$$

where $\eta(> 0)$ is the parameter indicating the degree of increase in the subjective probability of infection of more people going out. Moreover, we assume that the stigma cost is a decreasing function with the proportion of players going out in the total population as follows:

$$s(x) = \zeta_0 - \zeta_1 x, \tag{4}$$

where $\zeta_0(> 0)$ is the fixed stigma cost, $\zeta_1 x$ is the flexible stigma cost, and $\zeta_1(> 0)$ is the degree of stigma reduction of more people going out. This formulation of stigma cost is based on Lindbeck et al. (1999) and Katafuchi et al. (2020). We assume that $s(1) = \zeta_0 - \zeta_1 > 0$. This assumption means that the lowest level of stigma cost is not zero and positive. We make the following assumption:

Assumption 1

$$\eta c > \sigma \zeta_1 \tag{5}$$

Assumption (1) implies that the marginal cost of increasing the number of players going out is higher than their marginal benefit.

3 Replicator dynamics

Next, we show the replicator dynamics of the population share of players going out in the model. To achieve this, we need to check the expected payoff of each strategy. The expected payoff of going out and staying home are, respectively:

$$E_{[G]} = x\pi_{GG} + (1-x)\pi_{GS}, \tag{6}$$

and

$$E_{[S]} = x\pi_{SG} + (1-x)\pi_{SS}. \tag{7}$$

We model the replicator dynamics of the going-out share in the total population by the following differential equation:

$$\dot{x} = x(1-x)(E_{[G]} - E_{[S]}). \tag{8}$$

Substituting Equations (1) and (2) into Equation (9), we can transform Equation (8) as follows:

$$\dot{x} = x(1-x)\left[u_{\text{out}} - u_{\text{home}} - \gamma(x)c - \sigma s(x)\right]. \tag{9}$$

We derive the stationary point in the dynamics by solving (9), $\dot{x} = 0$, as follows:

$$x^* = 0, \hat{x}, 1, \tag{10}$$

where

$$\hat{x} = \frac{u_{\text{out}} - u_{\text{home}} - \sigma\zeta_0}{\eta c - \sigma\zeta_1}. \tag{11}$$

The condition for the interior stationary point is given, as shown in Lemma 1.

Lemma 1 *The necessary and sufficient condition for $\hat{x} \in (0, 1)$, is given by*

$$\sigma\zeta_0 < u_{\text{out}} - u_{\text{home}} < \eta c + \sigma(\zeta_0 - \zeta_1) \tag{12}$$

Proof. First, the condition for $\hat{x}$ is positive is given by

$$\begin{aligned} \hat{x} &> 0, \\ \frac{u_{\text{out}} - u_{\text{home}} - \sigma\zeta_0}{\eta c - \sigma\zeta_1} &> 0, \\ u_{\text{out}} - u_{\text{home}} - \sigma\zeta_0 &> 0, \end{aligned}$$

Hence,

$$u_{\text{out}} - u_{\text{home}} > \sigma\zeta_0. \tag{13}$$

Second, the condition for $\hat{x}$ is less than 1 is given by

$$\begin{aligned} \hat{x} &< 1, \\ \frac{u_{\text{out}} - u_{\text{home}} - \sigma\zeta_0}{\eta c - \sigma\zeta_1} &< 1, \\ u_{\text{out}} - u_{\text{home}} - \sigma\zeta_0 &< \eta c - \sigma\zeta_1, \end{aligned}$$

Thus,

$$u_{\text{out}} - u_{\text{home}} < \eta c + \sigma(\zeta_0 - \zeta_1). \tag{14}$$

From Conditions (13) and (14), the necessary and sufficient condition in order that $\hat{x} \in (0, 1)$ is given by

$$\sigma\zeta_0 < u_{\text{out}} - u_{\text{home}} < \eta c + \sigma(\zeta_0 - \zeta_1).$$

■

The stability analysis presents us with the following results:

Proposition 1 *The interior stationary point $x^* = \hat{x}$ is uniquely stable and $x^* = 0, 1$ is unstable if an interior steady state exists.*

Proof. We use the linear approximation method to check the stability in the stationary point. Differentiating $\dot{x}$ with respect to x yields the following result:

$$\frac{d\dot{x}}{dx} = (1 - 2x)\left[u_{\text{out}} - u_{\text{home}} - \gamma(x)c - \sigma s(x)\right] - x(1 - x)\left[\gamma'(x)c + \sigma s'(x)\right]. \tag{15}$$

First, we check the stability condition for $x^* = 0$. Substituting $x^* = 0$ into Equation (15), we obtain the following results:

$$\left.\frac{d\dot{x}}{dx}\right|_{x^*=0} = u_{\text{out}} - u_{\text{home}} - \sigma\zeta_0. \tag{16}$$

Thus, the stationary point $x^* = 0$ is stable if $u_{\text{out}} - u_{\text{home}} < \sigma\zeta_0$ and is otherwise unstable.

Second, we check the stability condition for $x^* = \hat{x}$. Substituting $x^* = \hat{x}$ into Equation (15), we obtain the following results:

$$\left.\frac{d\dot{x}}{dx}\right|_{x^*=\hat{x}} = -\hat{x}(1 - \hat{x})\left[\eta c - \sigma\zeta_1\right]. \tag{17}$$

The sign of (17) is negative from Assumption 1. Thus, the stationary point $x^* = x_1$ is stable.

Third, we confirm the stability condition for $x^* = 1$. Substituting $x^* = 1$ into Equation (15), we obtain the following results:

$$\left.\frac{d\dot{x}}{dx}\right|_{x^*=1} = -\left[u_{\text{out}} - u_{\text{home}} - \eta c - \sigma(\zeta_0 - \zeta_1)\right]. \tag{18}$$

Hence, the stationary point $x^* = 1$ is stable if $u_{\text{out}} - u_{\text{home}} > \eta c + \sigma(\zeta_0 - \zeta_1)$ and unstable otherwise.

Summing up the above stability conditions and Lemma 1, we conclude that the interior steady state $x^* = \hat{x}$ is uniquely stable and $x^* = 0, 1$ are unstable if an interior steady state exists. ■

Proposition 1 suggests that the interior steady state, $\hat{x}$, is stable when it exists. Figure 1 shows the dynamics of the population share of players going out and stationary points. There are three stationary points, $x^* = 0, \hat{x}, 1$. We can confirm that $x^* = \hat{x}$ is stable and $x^* = 0, 1$ are unstable, as Figure 1 shows.

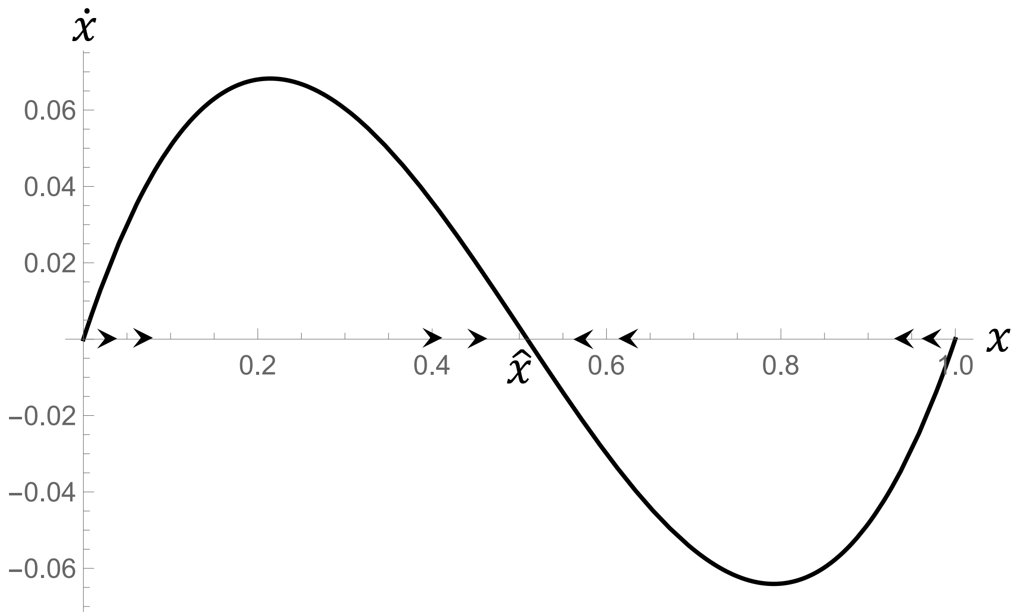

Figure 1: Steady states without the state of emergency
Notes: The figure shows the evolution of x with parameters as follows: $u_{\text{out}} = 1$, $u_{\text{home}} = 0.05$, $\eta = 1$, $c = 1.5$,$\sigma = 0.5$, $\zeta_0 = 0.5$, and $\zeta_1 = 0.25$.

4 Effect of the non-legally binding state of emergency

Our aim is to investigate the effect of the non-legally binding policy on the stationary point. We introduce the policy variable $\iota \in \{0, 1\}$ as follows:

$$\pi_{GG} = \pi_{GS} = u_{\mathrm{out}} - \gamma(x)c - (1 + \rho\iota)\sigma s(x), \tag{19}$$

where ι is the indicator variable of the state of emergency and $\rho > 0$ is a parameter that expresses the amplification of stigma by the state of emergency. Therefore, this setting implies that stigma costs are enhanced by $(1 + \rho)$ times more under the state of emergency than they would otherwise be. Let $\hat{x}_1$ denote the interior stationary point under the state of emergency and $\hat{x}_0$ without the state of emergency. $\hat{x}_0$ is equal to the right-hand side of (11) because $\hat{x} = \hat{x}_0$. The stationary points without the state of emergency are given as follows:

$$x^* = 0, \hat{x}_0, 1, \tag{20}$$

where

$$\hat{x}_0 = \frac{u_{\mathrm{out}} - u_{\mathrm{home}} - \sigma\zeta_0}{\eta c - \sigma\zeta_1}. \tag{21}$$

We can derive the stationary point under the state of emergency as follows:

$$x^* = 0, \hat{x}_1, 1, \tag{22}$$

where

$$\hat{x}_1 = \frac{u_{\mathrm{out}} - u_{\mathrm{home}} - (1 + \rho)\sigma\zeta_0}{\eta c - (1 + \rho)\sigma\zeta_1}. \tag{23}$$

The condition for the interior stationary point to exist under the state of emergency is given as shown in Lemma 2.

Lemma 2 *The necessary and sufficient condition in order that $\hat{x}_{\iota=1} \in (0, 1)$ under the state of* *emergency is given by*

$$(1+\rho)\sigma\zeta_0 < u_{\text{out}} - u_{\text{home}} < \eta c + (1+\rho)\sigma(\zeta_0 - \zeta_1), \tag{24}$$

Proof. First, the condition for $\hat{x}$ is positive is given by

$$\begin{aligned} \hat{x}_{\iota=1} &> 0, \\ \frac{u_{\text{out}} - u_{\text{home}} - (1+\rho)\sigma\zeta_0}{\eta c - (1+\rho)\sigma\zeta_1} &> 0, \\ u_{\text{out}} - u_{\text{home}} - (1+\rho)\sigma\zeta_0 &> 0, \end{aligned}$$

Hence,

$$u_{\text{out}} - u_{\text{home}} > (1+\rho)\sigma\zeta_0. \tag{25}$$

Second, the condition for $\hat{x}$ is less than 1 is given by

$$\begin{aligned} \hat{x}_{\iota=1} &< 1, \\ \frac{u_{\text{out}} - u_{\text{home}} - (1+\rho)\sigma\zeta_0}{\eta c - (1+\rho)\sigma\zeta_1} &< 1, \\ u_{\text{out}} - u_{\text{home}} - (1+\rho)\sigma\zeta_0 &< \eta c - (1+\rho)\sigma\zeta_1, \end{aligned}$$

Thus,

$$u_{\text{out}} - u_{\text{home}} < \eta c + (1+\rho)\sigma(\zeta_0 - \zeta_1). \tag{26}$$

From Conditions (25) and (26), the necessary and sufficient condition to ensure that $\hat{x}_{\iota=1} \in (0,1)$ is given by

$$(1+\rho)\sigma\zeta_0 < u_{\text{out}} - u_{\text{home}} < \eta c + (1+\rho)\sigma(\zeta_0 - \zeta_1).$$

■

Lemma 2 shows that the conditions for the existence of the interior stationary point under the non-legally binding state of emergency is similar to that in 1.

The stability analysis at the stationary points under the state of emergency presents the following results:

Proposition 2 *Under the state of emergency, the interior stationary point* $x^* = \hat{x}_1$ *is uniquely stable and* $x^* = 0, 1$ *is unstable if the interior steady state exists.*

Proof. We use the linear approximation method to investigate the stability at the stationary point. The replicator dynamics of the population share of players going out is given by

$$\dot{x}|_{\iota=1} = x(1-x)\left[u_{\text{out}} - u_{\text{home}} - \gamma(x)c - (1+\rho)\sigma s(x)\right]. \tag{27}$$

Differentiating (27) with respect to x yields the following result:

$$\frac{d\dot{x}}{dx} = (1-2x)\left[u_{\text{out}} - u_{\text{home}} - \gamma(x)c - (1+\rho)\sigma s(x)\right] - x(1-x)\left[\gamma'(x)c + (1+\rho)\sigma s'(x)\right]. \tag{28}$$

First, we check the stability condition for $x^* = 0$. Substituting $x^* = 0$ into Equation (28), we obtain the following results:

$$\left.\frac{d\dot{x}}{dx}\right|_{x^*=0} = u_{\text{out}} - u_{\text{home}} - (1+\rho)\sigma\zeta_0. \tag{29}$$

Thus, the stationary point $x^* = 0$ is stable if $u_{\text{out}} - u_{\text{home}} < (1+\rho)\sigma\zeta_0$ and is otherwise unstable.

Second, we check the stability condition for $x^* = \hat{x}_1$. Substituting $x^* = \hat{x}_1$ into Equation (28), we obtain the following results:

$$\left.\frac{d\dot{x}}{dx}\right|_{x^*=\hat{x}_1} = -\hat{x}_{\iota=1}(1-\hat{x}_{\iota=1})\left[\eta c - (1+\rho)\sigma\zeta_1\right]. \tag{30}$$

The sign of (30) is negative because Assumption (1). Thus, the stationary point $x^* = \hat{x}_1$ is stable.

Third, we confirm the stability condition for $x^* = 1$. Substituting $x^* = 1$ into Equation (28), we obtain the following results:

$$\left.\frac{d\dot{x}}{dx}\right|_{x^*=1} = -\left[u_{\text{out}} - u_{\text{home}} - \eta c - (1+\rho)\sigma(\zeta_0 - \zeta_1)\right]. \tag{31}$$

Hence, the stationary point $x^* = 1$ is stable if $u_{\text{out}} - u_{\text{home}} > (1+\rho)\eta c + \sigma(\zeta_0 - \zeta_1)$ and unstable otherwise. By summing up the above stability conditions and Lemma 2, we conclude that the interior steady state $x^* = \hat{x}_1$ is uniquely stable and $x^* = 0, 1$ are unstable if an interior steady state exists. ■

Proposition 2 shows that the interior stationary point is stable and other stationary points are unstable, although there are three stationary points, $x^* = 0, \hat{x}_1, 1$, as in Proposition 1. From Proposition 1 and 2, we need to compare each interior stationary point to consider the effect of the non-legal policy as the state of emergency.

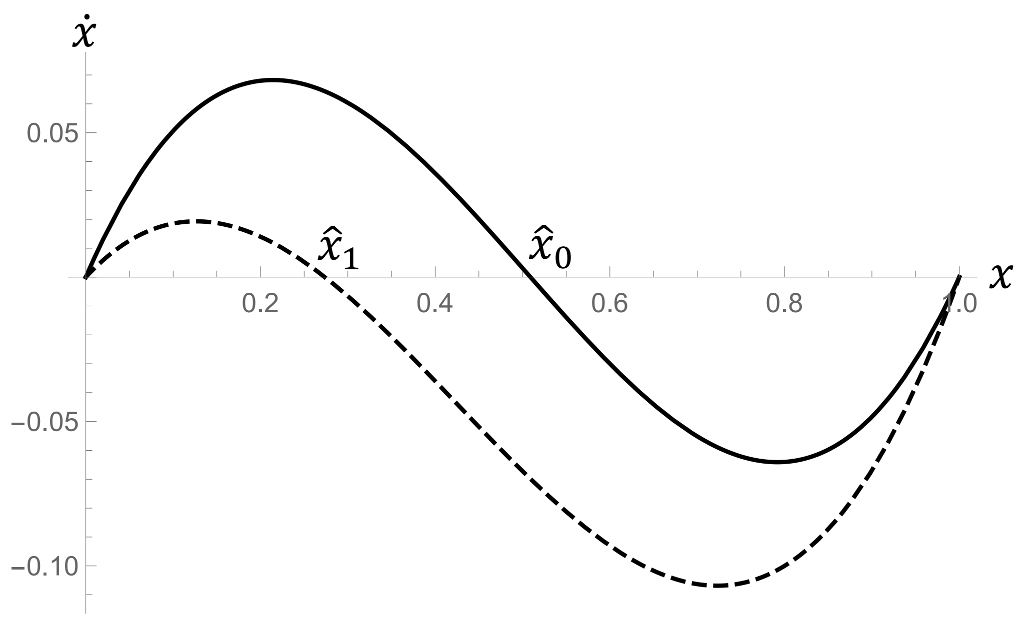

Figure 2: Effect of the state of emergency
Notes: The figure shows the numerical plot of $\dot{x}|_{\iota=0}$ drawn by solid line and $\dot{x}|_{\iota=1}$ drawn by dash line with parameters as follows: $u_{\text{out}} = 1$, $u_{\text{home}} = 0.05$, $\eta = 1$, $c = 1.5$, $\sigma = 0.5$, $\zeta_0 = 0.5$, $\zeta_1 = 0.25$, $\rho = 1.5$.

We obtain the following proposition about the effects of the state of emergency.

Proposition 3 *The state of emergency, which is a non-legally binding policy, has the effect of restraining the player's going-out behavior, that is,* $\hat{x}_1 - \hat{x}_0 < 0$*, under the following condition:*

$$u_{\text{out}} - u_{\text{home}} < \frac{\zeta_0}{\zeta_1}\eta c. \tag{32}$$

Proof. The difference between $\hat{x}_1$ and $\hat{x}_0$ is given as follows:

$$\hat{x}_1 - \hat{x}_0 = \frac{u_{\text{out}} - u_{\text{home}} - (1+\rho)\sigma\zeta_0}{\eta c - (1+\rho)\sigma\zeta_1} - \frac{u_{\text{out}} - u_{\text{home}} - \sigma\zeta_0}{\eta c - \sigma\zeta_1}, \tag{33}$$

From (33), the condition for $\hat{x}_1 - \hat{x}_0 < 0$ is given by

$$u_{\text{out}} - u_{\text{home}} < \frac{\zeta_0}{\zeta_1}\eta c. \tag{34}$$

■

Proposition 3 suggests that a declaration of a state of emergency that is not legally binding discourages people from going out, which is consistent with the results of Katafuchi et al. (2020) that the number of people who go out reduces significantly under a state of emergency, although the climate and other factors are controlled.

Figure 2 shows the numerical plot of the evolution of x with and without the non-legally binding state of emergency. The stable interior stationary point uniquely exists in each evolution. We can visually confirm that $\hat{x}_1$ is lower than $\hat{x}_0$, that is, the non-legally binding state of emergency can reduce the share of going-out players through self-restraint behavior.

The condition (32) in Proposition 3 means that the state of emergency is effective when the gain from going out is low, fixed stigma cost is high, degree of stigma reduction of players going out is higher, cost of infection is high, and the degree of increase in the subjective probability of infection of more players going out is high.

5 Comparative static analysis

We conduct a comparative static analysis to investigate the impact of varying each parameter (u_{out}, u_{home}, η, c, σ, ρ, ζ_0, and ζ_1) on the equilibrium number of players going out. We summarize the results in the following proposition:

Proposition 4 *Results in the comparative static analysis are given as follows:*

1. *An increase in the utility from going out (u_{out}) **raises** the equilibrium share of players going out in the total population under the state of emergency and without it.*

2. *An increase in the utility from staying home (u_{home}) **reduces** the equilibrium share of players going out in the total population under the state of emergency and without it.*

3. *An increase in the degree of rise in the subjective probability of infection of more people going out (η) **reduces** the equilibrium share of players going out in the total population under the state of emergency and without it.*

4. *An increase in the cost of infection (c) **reduces** the equilibrium share of players going out in the total population under the state of emergency and without it.*

5. *An increase in the relative size of stigma (σ) **reduces or increases** the equilibrium share of players going out in the total population under the state of emergency and without it.*

6. *An increase in the degree of stigma amplified by the state of emergency (ρ) **reduces or increases** the equilibrium share of players going out in the total population under the state of emergency whereas it **does not affect** the share without the state of emergency.*

7. *An increase in the fixed stigma cost (ζ_0) **reduces** the equilibrium share of players going out in the total population under the state of emergency and without it.*

8. *An increase in the degree of stigma reduction of more people going out (ζ_1) **raises** the equilibrium share of players going out in the total population under the state of emergency and without it.*

Proof.

1. We investigate the effect of an increase in the utility from going out in the equilibrium. The effect on the equilibrium under the state of emergency is given as follows:

$$\frac{\partial \hat{x}_1}{\partial u_{\text{out}}} = \frac{1}{\eta c - (1+\rho)\sigma\zeta_1} > 0, \tag{35}$$

while the effect on the equilibrium without the state of emergency is given by

$$\frac{\partial \hat{x}_0}{\partial u_{\text{out}}} = \frac{1}{\eta c - \sigma\zeta_1} > 0. \tag{36}$$

2. The effect of an increase in the utility from staying home on the equilibrium under the state of emergency is given as follows:

$$\frac{\partial \hat{x}_1}{\partial u_{\text{out}}} = -\frac{1}{\eta c - (1+\rho)\sigma\zeta_1} < 0, \tag{37}$$

while the effect on the equilibrium without the state of emergency is given by

$$\frac{\partial \hat{x}_0}{\partial u_{\text{out}}} = -\frac{1}{\eta c - \sigma\zeta_1} < 0. \tag{38}$$

3. The effect of an increase in the degree of rise in the subjective probability of infection of more people going out on the equilibrium under the state of emergency is given as follows:

$$\frac{\partial \hat{x}_1}{\partial \eta} = -\frac{c\left[u_{\text{out}} - u_{\text{home}} - (1+\rho)\sigma\zeta_0\right]}{\left[\eta c - (1+\rho)\sigma\zeta_1\right]^2} < 0, \tag{39}$$

while the effect on the equilibrium without the state of emergency is given by

$$\frac{\partial \hat{x}_0}{\partial \eta} = -\frac{c\left[u_{\text{out}} - u_{\text{home}} - \sigma\zeta_0\right]}{\left(\eta c - \sigma\zeta_1\right)^2} < 0. \tag{40}$$

4. The effect of an increase in the cost of infection on the equilibrium under the state of emergency is given as follows:

$$\frac{\partial \hat{x}_1}{\partial \eta} = -\frac{\eta\left[u_{\text{out}} - u_{\text{home}} - (1+\rho)\sigma\zeta_0\right]}{\left[\eta c - (1+\rho)\sigma\zeta_1\right]^2} < 0, \tag{41}$$

while the effect on the equilibrium without the state of emergency is given by

$$\frac{\partial \hat{x}_0}{\partial \eta} = -\frac{\eta\left[u_{\text{out}} - u_{\text{home}} - \sigma\zeta_0\right]}{\left(\eta c - \sigma\zeta_1\right)^2} < 0. \tag{42}$$

5. The effect of an increase in the relative size of stigma on the equilibrium under the state of

emergency is given as follows:

$$\frac{\partial \hat{x}_1}{\partial \sigma} = -\frac{(1+\rho)\zeta_0}{\eta c - (1+\rho)\sigma\zeta_1} + \frac{\left[u_{\text{out}} - u_{\text{home}} - (1+\rho)\sigma\zeta_0\right](1+\rho)\zeta_1}{\left[\eta c - (1+\rho)\sigma\zeta_1\right]^2} \gtreqless 0, \tag{43}$$

while the effect on the equilibrium without the state of emergency is given by

$$\frac{\partial \hat{x}_0}{\partial \sigma} = -\frac{\zeta_0}{\eta c - \sigma\zeta_1} + \frac{\left(u_{\text{out}} - u_{\text{home}} - \sigma\zeta_0\right)\zeta_1}{\left(\eta c - \sigma\zeta_1\right)^2} \gtreqless 0. \tag{44}$$

6. The effect of an increase in the degree of stigma amplified by the state of emergency on the equilibrium under the state of emergency is given as follows:

$$\frac{\partial \hat{x}_1}{\partial \rho} = -\frac{\sigma\zeta_0}{\eta c - (1+\rho)\sigma\zeta_1} + \frac{\left[u_{\text{out}} - u_{\text{home}} - (1+\rho)\sigma\zeta_0\right]\sigma\zeta_1}{\left[\eta c - (1+\rho)\sigma\zeta_1\right]^2} \gtreqless 0, \tag{45}$$

while the effect on the equilibrium without the state of emergency is given by

$$\frac{\partial \hat{x}_0}{\partial \rho} = 0. \tag{46}$$

7. The effect of an increase in the fixed stigma cost on the equilibrium under the state of emergency is given as follows:

$$\frac{\partial \hat{x}_1}{\partial \zeta_0} = -\frac{(1+\rho)\sigma}{\eta c - (1+\rho)\sigma\zeta_1} < 0, \tag{47}$$

while the effect on the equilibrium without the state of emergency is given by

$$\frac{\partial \hat{x}_0}{\partial \zeta_0} = -\frac{\sigma}{\eta c - \sigma\zeta_1} < 0. \tag{48}$$

8. The effect of an increase in the degree of stigma reduction of more people going out on the equilibrium under the state of emergency is given as follows:

$$\frac{\partial \hat{x}_1}{\partial \zeta_1} = \frac{(1+\rho)\sigma\left[u_{\text{out}} - u_{\text{home}} - (1+\rho)\sigma\zeta_0\right]}{\left[\eta c - (1+\rho)\sigma\zeta_1\right]^2} > 0, \tag{49}$$

while the effect on the equilibrium without the state of emergency is given by

$$\frac{\partial \hat{x}_0}{\partial \zeta_1} = \frac{\sigma\left[u_{\text{out}} - u_{\text{home}} - \sigma\zeta_0\right]}{\left(\eta c - \sigma\zeta_1\right)^2} > 0. \tag{50}$$

■

Most of the results of Proposition 4 are consistent with our supposition. In fact, an increase in the utility from going out (u_{out}) and the degree of stigma reduction of more people going out (ζ_1) raise the number of players going out, because the incentive to go out increases. In contrast, an increase in the utility from staying home (u_{home}), degree of increase in the subjective probability of infection of more people going out (η), cost of infection (c), and the fixed stigma cost (ζ_0), reduce the number of players going out, because the incentive to go out decreases.

However, an increase in the relative size of stigma σ and the degree of stigma amplified by the state of emergency ρ can raise or reduce the number of players going out, although intuitively it reduces that. This result arises from the indirect effect that occurs through the channel as follows: First, intensifying the stigma cost reduces the number of players going out. Second, a decrease in players going out reduces infection risk, and finally, players have an incentive to go out from the weakening infection risk.

6 Welfare analysis

We now conduct the welfare analysis. Let W denote social welfare, which is given by

$$\begin{aligned} W &= xE_{[G]} + (1-x)E_{[S]}, \\ &= x\left[u_{\text{out}} - \gamma(x)c - (1+\iota\rho)\sigma s(x)\right] + (1-x)u_{\text{home}}, \\ &= x\left[u_{\text{out}} - \eta c x - (1+\iota\rho)\sigma\left(\zeta_0 - \zeta_1 x\right)\right] + (1-x)u_{\text{home}}. \end{aligned} \tag{51}$$

Let x^{opt} denote the socially optimal level of population share of players going out. The following proposition presents the relationship between the equilibrium level and the socially optimal level of x:

Proposition 5 *The interior equilibrium level of the population share of players going out is larger* *than the socially optimal level without/under the state of emergency, that is,* $\hat{x}_0 > x_0^{\text{opt}}$, $\hat{x}_1 > x_1^{\text{opt}}$.

Proof. Substituting $\iota = 0$ into Equation (51), we obtain the following:

$$W(x)|_{\iota=0} = x\left[u_{\text{out}} - \eta c x - \sigma\left(\zeta_0 - \zeta_1 x\right)\right] + (1-x)u_{\text{home}}. \tag{52}$$

The first order condition and the second order condition are given by

$$\frac{dW(x)|_{\iota=0}}{dx} = u_{\text{out}} - u_{\text{home}} - \sigma\zeta_0 + 2(\sigma\zeta_1 - \eta c)x, \tag{53}$$

$$\frac{d^2W(x)|_{\iota=0}}{dx^2} = 2(\sigma\zeta_1 - \eta c) < 0. \tag{54}$$

The socially optimal level of population share of going-out players without the state of emergency is as follows:

$$x_0^{\text{opt}} = \frac{u_{\text{out}} - u_{\text{home}} - \sigma\zeta_0}{2\left[\eta c - \sigma\zeta_1\right]} < \frac{u_{\text{out}} - u_{\text{home}} - \sigma\zeta_0}{\eta c - \sigma\zeta_1} = \hat{x}_0. \tag{55}$$

Next, substituting $\iota = 1$ into Equation (51), we obtain the following:

$$W(x)|_{\iota=1} = x\left[u_{\text{out}} - \eta c x - (1+\rho)\sigma\left(\zeta_0 - \zeta_1 x\right)\right] + (1-x)u_{\text{home}}. \tag{56}$$

The first order condition and the second order condition are given by

$$\frac{dW(x)|_{\iota=1}}{dx} = u_{\text{out}} - u_{\text{home}} - (1+\rho)\sigma\zeta_0 + 2\left[(1+\rho)\sigma\zeta_1 - \eta c\right]x, \tag{57}$$

$$\frac{d^2W(x)|_{\iota=1}}{dx^2} = 2\left[(1+\rho)\sigma\zeta_1 - \eta c\right]x < 0. \tag{58}$$

The socially optimal level of population share of players going out under the state of emergency is as follows:

$$x_1^{\text{opt}} = \frac{u_{\text{out}} - u_{\text{home}} - (1+\rho)\sigma\zeta_0}{2\left[\eta c - (1+\rho)\sigma\zeta_1\right]} < \frac{u_{\text{out}} - u_{\text{home}} - (1+\rho)\sigma\zeta_0}{\eta c - (1+\rho)\sigma\zeta_1} = \hat{x}_1. \tag{59}$$

■

Proposition 5 suggests that the level of population share of players going out in the interior equilibrium is larger than the socially optimal level without the state of emergency, and it is the same under the state of emergency. The existence of externality in the model generates these results. Infection risk is assumed to be the increasing function with respect to the population share of going-out players and stigma is assumed to be the decreasing function. That is, an increase in the number of people going out creates a negative externality of higher risk of infection and a positive externality of weaker stigma. Because each player considers the externalities for individual level, the equilibrium population share of players going out is excessive compared to the socially optimal level.

7 Conclusion

This study analyzes the interaction between self-restraint behavior, infection risk, and stigma against going out during a pandemic, using replicator dynamics. Consequently, the population share of going-out players has three steady states, as follows: $x^* = 0, \hat{x}, 1$; however, the interior stationary point, $\hat{x}$, is only stable (Proposition 1). We show that the non-legally binding policy reduces the number of people going out in the steady state by intensifying stigma costs (Proposition 3). This result is consistent with the empirical result in Katafuchi et al. (2020). Our comparative static analysis indicates that intensifying the stigma cost does not necessarily induce the reduction in the number of players going out because of the indirect effect of the decrease in infection risk (Proposition 4). This suggests the policy implication that possibly, intensifying social pressure cannot reduce going-out behavior. Finally, the welfare analysis shows that the number of players going out is larger than the socially optimal level without/under the state of emergency (Proposition 5).

This study does not take into account any self-restraint on the part of suppliers, such as restaurants. However, the "self-restraint police" stigmatized not only people outdoors but also restaurants operating in a declared state of emergency. We will need to analyze supply-side and household restraint behavior and for changes in the number of people infected and the economy. Our model assumes that stigma cost and infection risk are linear functions with respect to the population share of people going out. We will give their functions a micro-foundation for future work.

Social stigma is important in the fight against COVID-19 because it reduces the spread of infection through individual self-restraint behavior. However, we must be vigilant of the negative side of stigma or social pressures, because, as history shows, extreme stigmatization can lead to discrimination, prejudice, and violence.

References

Acemoglu, D., V. Chernozhukov, I. Werning, and M. D. Whinston (2020): "A multi-risk SIR model with optimally targeted lockdown," *NBER Working Paper*, URL: `https://www.nber.org/papers/w27102`, (Accessed on July 11, 2020).

Alger, I., J. W. Weibull, and L. Lehmann (2020): "Evolution of preferences in structured populations: genes, guns, and culture," *Journal of Economic Theory*, 185, 104951.

Alvarez, F. E., D. Argente, and F. Lippi (2020): "A simple planning problem for covid-19 lockdown," *NBER Working Paper*, URL: `https://www.nber.org/papers/w26981`, (Accessed on July 11, 2020).

AS (2020): "Coronavirus: Spain fines over 1 million lockdown dodgers," URL: `https://en.as.com/en/2020/05/20/other_sports/1590007192_285496.html` (Accessed on October 4, 2020).

Besley, T. and S. Coate (1992): "Understanding welfare stigma: Taxpayer resentment and statistical discrimination," *Journal of Public Economics*, 48, 165–183.

Bhargava, S. and D. Manoli (2015): "Psychological Frictions and the Incomplete Take-Up of Social Benefits: Evidence from an IRS Field Experiment," *American Economic Review*, 105, 3489–3529.

Cerqueti, R., L. Correani, and G. Garofalo (2013): "Economic interactions and social tolerance: A dynamic perspective," *Economics Letters*, 120, 458–463.

COVID-19 Situazione Italia (2020): "COVID-19 Italia," URL: `https://opendathunadpc.maps.arcgis.com/apps/opsdashboard/index.html#/b0c68bce2cce478eaac82fe38d4138b1` (Accessed on October 4, 2020).

Eichenbaum, M. S., S. Rebelo, and M. Trabandt (2020): "The Macroeconomics of Testing and Quarantining," *NBER Working Paper*, URL: `https://www.nber.org/papers/w27104`, (Accessed on July 11, 2020).

Ennis, H. M. and J. A. Weinberg (2013): "Over-the-counter loans, adverse selection, and stigma in the interbank market," *Review of Economic Dynamics*, 16, 601–616.

Farboodi, M., G. Jarosch, and R. Shimer (2020): "Internal and external effects of social distancing in a pandemic," *NBER Working Paper*, URL: `https://www.nber.org/papers/w27059`, (Accessed on July 11, 2020).

France 24 (2020): "French National Assembly greenlights coronavirus 'public health emergency' bill," URL: `https://www.france24.com/en/20200322-coronavirus-french-national-assembly-greenlights-public-health-emergency-bill` (Accessed on October 4, 2020).

Gharehgozli, O., P. Nayebvali, A. Gharehgozli, and Z. Zamanian (2020): "Impact of COVID-19 on the Economic Output of the US Outbreak's Epicenter," *Economics of Disasters and Climate Change*.

Goffman, E. (1963): *Stigma: Notes on the Management of Spoiled Identity*, Prentice-Hall.

Holtemöller, O. (2020): "Integrated assessment of epidemic and economic dynamics," *IWH Discussion Papers*, URL: `https://www.econstor.eu/bitstream/10419/215895/1/1694465632.pdf`, (Accessed on July 11, 2020).

Itaya, J. and K. Kurita (2020): "Replicator evolution of welfare stigma: Welfare fraud vs incomplete take-up," *CESifo Working Paper*, 1–29, URL: `https://www.cesifo.org/en/publikationen/2020/working-paper/replicator-evolution-welfare-stigma-welfare-fraud-vs-incomplete`, (Accessed on November 5, 2020).

Iwasaki, A. and N. D. Grubaugh (2020): "Why does Japan have so few cases of COVID-19?" *EMBO Molecular Medicine*, 12, e12481.

Kandori, M., G. J. Mailath, and R. Rob (1993): "Learning, mutation, and long run equilibria in games," *Econometrica: Journal of the Econometric Society*, 29–56.

Katafuchi, Y., K. Kurita, and S. Managi (2020): "COVID-19 with stigma: Theory and evidence from mobility data," *Economics of Disasters and Climate Change*, 1–25.

Kim, Y. (2003): "Income distribution and equilibrium multiplicity in a stigma-based model of tax evasion," *Journal of Public Economics*, 87, 1591–1616.

Kobayashi, G., S. Sugasawa, H. Tamae, and T. Ozu (2020): "Predicting intervention effect for COVID-19 in Japan: state space modeling approach," *BioScience Trends*.

Kurita, K., Y. Katafuchi, and N. Hori (2020): "Stigma model of welfare fraud and non-take-up: Theory and evidence from OECD panel data," *International Journal of Economic Theory*, 1–29.

Kyodo News (2020): "Morning crowds down 60% in central Tokyo after emergency declared," URL: `https://english.kyodonews.net/news/2020/04/4394741a8810-morning-crowds-down-60-in-central-tokyo-after-emergency-declared.html` (Accessed on July 11, 2020).

Lindbeck, A., S. Nyberg, and J. W. Weibull (1999): "Social norms and economic incentives in the welfare state," *The Quarterly Journal of Economics*, 114, 1–35.

Lu, N., K.-W. Cheng, N. Qamar, K.-C. Huang, and J. A. Johnson (2020): "Weathering COVID-19 storm: successful control measures of five Asian countries," *American Journal of Infection Control*, 48, 851–852.

Major, B., J. F. Dovidio, and B. G. Link (2018): *The Oxford handbook of stigma, discrimination, and health*, Oxford University Press.

Mandel, A. and V. Veetil (2020): "The Economic Cost of COVID Lockdowns: An Out-of-Equilibrium Analysis," *Economics of Disasters and Climate Change*.

Martin, A., M. Markhvida, S. Hallegatte, and B. Walsh (2020): "Socio-Economic Impacts of COVID-19 on Household Consumption and Poverty," *Economics of Disasters and Climate Change*.

Moffitt, R. (1983): "An economic model of welfare stigma," *American economic review*, 73, 1023–1035.

Norman, T. W. (2020): "The evolution of monetary equilibrium," *Games and Economic Behavior*.

Rasmusen, E. (1996): "Stigma and self-fulfilling expectations of criminality," *The Journal of Law and Economics*, 39, 519–543.

Safarzyńska, K. and J. C. van den Bergh (2010): "Evolutionary models in economics: a survey of methods and building blocks," *Journal of Evolutionary Economics*, 20, 329–373.

Safarzyńska, K. and J. C. Van den Bergh (2011): "Beyond replicator dynamics: Innovation–selection dynamics and optimal diversity," *Journal of Economic Behavior & Organization*, 78, 229–245.

Shi, Y., M. Pan, and D. Peng (2017): "Replicator dynamics and evolutionary game of social tolerance: The role of neutral agents," *Economics Letters*, 159, 10–14.

Taylor, P. D. and L. B. Jonker (1978): "Evolutionary stable strategies and game dynamics," *Mathematical biosciences*, 40, 145–156.

The COVID Tracking Project (2020): "Our DATA," URL: `https://covidtracking.com/data` (Accessed on October 4, 2020).

The Japan Times (2020a): "Japan cautiously lifts last of virus emergency controls," URL: `https://www.japantimes.co.jp/news/2020/05/25/national/japan-lifts-state-of-emergency-coronavirus/` (Accessed on July 11, 2020).

——— (2020b): "Japan's 'virus vigilantes' take on rule-breakers and invaders," URL: `https://www.japantimes.co.jp/news/2020/05/13/national/coronavirus-vigilantes-japan/` (Accessed on July 11, 2020).

——— (2020c): "Understanding the need to shame someone on social media for not exercising self-restraint during a pandemic," URL: https://www.japantimes.co.jp/news/2020/05/16/national/media-national/social-media-shaming-coronavirus/ (Accessed on July 11, 2020).

Weibull, J. W. (1997): *Evolutionary game theory*, MIT press.

WHO (2020): "Coronavirus disease 2019 (COVID-19): situation report, 172," URL: https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200710-covid-19-sitrep-172.pdf?sfvrsn=70724b90_2 (Accessed on October 2, 2020).

Wood, A. D., C. F. Mason, and D. Finnoff (2016): "OPEC, the Seven Sisters, and oil market dominance: An evolutionary game theory and agent-based modeling approach," *Journal of Economic Behavior & Organization*, 132, 66–78.

Wu, J. (2018): "Entitlement to assort: Democracy, compromise culture and economic stability," *Economics Letters*, 163, 146–148.

——— (2019): "Labelling, homophily and preference evolution," *International Journal of Game Theory*, 1–22.

Yamamura, E. and Y. Tsutsui (2020): "Impact of the State of Emergency Declaration for COVID-19 on Preventive Behaviors and Mental Conditions in Japan: Difference in Difference Analysis using Panel Data," *arXiv preprint arXiv:2005.13008*.

Yang, Z., Y. Shi, and Y. Li (2018): "Analysis of intellectual property cooperation behavior and its simulation under two types of scenarios using evolutionary game theory," *Computers & Industrial Engineering*, 125, 739–750.