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The Credibility of Communication in a Pandemic

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Abstract

Social distancing measures are typically recommended to contain the spread of infectious diseases. To improve the public's voluntary compliance, governments and health authorities seek to publicize timely information about the pandemic. Yet social planners may exaggerate or downplay their private information about the disease's severity to elicit their preferred level of social distancing. This is because the relative weight they assign to the costs of isolation over public health may be unbalanced, and people may not fully consider how their social distancing may influence others' infection risk. Consequently, messages and claims about the pandemic may be distrusted. The author investigates whether and when communication can be fully or partially credible despite apparent incentives for misrepresentation. The author finds that a government would communicate truthfully in equilibrium if and only if the disease severity levels are not too close to each other in the public's prior belief. Nevertheless, an increasing difference between the severity levels need not enhance the credibility of communication. Greater communication credibility may hurt social welfare. Moreover, as the government becomes more concerned about the costs of social distancing, its equilibrium messages may become more or less trustworthy. The article's results can benefit social planners and users of their messages (e.g., analysts, researchers, investors).

Keywords

cheap talk, communication, COVID-19, pandemic, public health, social distancing

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Many contagious diseases are transmitted mainly through interpersonal contact. To halt the spread of infectious viruses, social planners usually implement policy measures that are aimed at reducing social interaction. For example, during the COVID-19 pandemic, many governments have issued stay-at-home or shelter-in-place orders to restrict mobility and physical activity, and social distancing measures (e.g., quarantine, isolation) have been strongly recommended by public health experts such as the World Health Organization and the Centers for Disease Control and Prevention (for quarantine and isolation guidelines, see Centers for Disease Control and Prevention [2022]). It is believed that the chance of infectious disease transmission could be mitigated if people keep sufficient physical distance and reduce the frequency of close contact with each other (e.g., work from home, restrict visits to crowded spaces such as gyms and restaurants, cancel mass gatherings, postpone trips) (Fowler et al. 2021; Hsiang et al. 2020).

In many societies (e.g., the United States), these measures are largely recommendations rather than ordinances; that is, their implementation usually hinges on voluntary compliance but not legal enforcement. Nevertheless, the adoption of social distancing measures can be individually costly and may lead to behavioral changes and disruptions to people's business, work, and life (Farboodi, Jarosch, and Shimer 2021). As a result, people may not always adhere to all the guidelines that restrict their social interaction (Simonov et al. 2022; Webster et al. 2020; Wright et al. 2020). To improve the public's voluntary compliance, governments and health authorities can provide timely information about the severity of the infectious disease as well as the benefits and the rationale of their policies and protocols (De Véricourt, Gurkan, and Wang 2021; Webster et al. 2020).

However, a policy maker's claims about a pandemic need not always be credible because, typically, the private and social interests are not perfectly aligned in adopting social distancing measures. People need not fully consider the impact of their quarantine or isolation on other people's infection risk (Farboodi, Jarosch, and Shimer 2021), and governments may not bear or care about all the costs of the public in restricting social activities. This may lead governments to exaggerate the risk of infection to induce more social distancing. Conversely, if a social planner weighs the negative impact of social distancing (e.g., on the economy) more than public health, it may

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downplay the severity and/or consequence of an infectious disease. In general, policy makers may be motivated to manipulate the public's belief and may not truthfully convey their insider knowledge and private information about the infectious disease. As a result, people may disbelieve the government's communication and disregard health authorities' recommendations to practice social distancing (Simonov et al. 2022; Webster et al. 2020). Alternatively, it is found that people were more likely to observe COVID-19 health guidelines as their trust in the government increased (e.g., Pak, McBryde, and Adegboye 2021).

For instance, there are numerous ways for social planners to manipulate the reported rate of infected cases, which is one of the most important indicators of the state and severity of a pandemic (e.g., Pagel and Yates 2021; Starnini et al. 2021). They can entertain the basis that defines the case date (e.g., infection, symptom onset, testing, diagnosis, notification) and/or the criteria to confirm cases, which are typically undisclosed or intentionally vague.[1] In addition, many governments deliberately reported false infection-related figures for COVID-19 and other disease outbreaks (e.g., Dubowitz and Ghasseminejad 2020; Lin et al. 2022; Richards 2020). Public administrators may convey deceptive messages about pandemics for political considerations.[2] Moreover, governments may support disinformation campaigns by deliberately generating and disseminating false information to deceive people during a pandemic (e.g., Lin et al. 2022; Richards 2020).[3]

My main objective in this research is to investigate the emergence of truthful communication about a pandemic when social planners can misrepresent their messages and claims. I examine the extent to which governments and public health authorities may credibly convey private information about the severity of disease infection to the public through cheap talk communication. I also evaluate the equilibrium welfare implications of the credibility/informativeness of communication. In addition, I study how the relative weight a policy maker assigns to the costs of social distancing versus public health may influence the equilibrium credibility of communication.

I consider the interaction between a government and a continuum of people in a pandemic. A person can be either infectious or susceptible. An infectious person has unknowingly contracted the virus and may transmit the disease to a susceptible person through an endogenous and behavior-dependent process. Each person can decide whether to incur a cost to exercise a high (vs. low) level of social distancing. The disease cannot be transmitted from an infectious and self-isolated person or to someone who is susceptible but socially inactive. However, if a susceptible person remains socially active, the probability that they will be infected is proportional to the number of infectious people who choose to be socially active. One distinguishing attribute of my infection model is that a person is unaware of their health state (infectious or susceptible) when the social distancing decision is made. This captures presymptomatic or asymptomatic disease transmission, which is an important feature of COVID-19 (Bai et al. 2020; Farboodi, Jarosch, and Shimer 2021).

The initial fraction of infectious people, which I call the "base infection rate," can be either high or low and is privately known to the government. The government can communicate the actual base infection rate to the public at will. Communication is cheap talk in the sense that it is costless and unverifiable. Upon receiving the government's message, people simultaneously and independently make their decisions on social distancing.

I show that the equilibrium proportion of self-isolated people increases as the disease becomes more contagious. However, the equilibrium level of social distancing first increases and then decreases with the base infection rate. This nonmonotonic effect arises because a higher base infection rate implies that a socially active person is not only more likely to be infectious to transmit the disease but also less likely to be susceptible such that the incremental risk of infection is smaller. That is, the marginal impact of social distancing on infection reduction is higher when the base infection rate is intermediate, rather than high or low. Moreover, the aggregate infection level across all people can first increase and then decrease as the disease becomes more contagious to induce more people to observe social distancing guidelines.

I demonstrate that there may exist a separating equilibrium whereby the government faithfully communicates with the public. When the government's objective is to maximize social welfare, it desires to encourage more social distancing than what would emerge in the equilibrium interaction among the individuals. This would motivate the government to distort its claims upward or downward (i.e., the mimicking incentive can go either way), depending on whether the high or the low base infection rate is intermediate relative to the other base infection rate. Yet a credible-communication equilibrium can arise if and only if the low base infection rate is sufficiently low or the high base infection rate is sufficiently high. However, an increasing gap between the two types of base infection rates may facilitate or undermine the emergence of the separating equilibrium.

I also identify conditions to sustain the existence of semiseparating equilibrium whereby the government of one type (high or low) communicates faithfully but the other type mixes between truthful and false reporting. The semiseparating equilibrium may emerge even when the separating equilibrium does not exist, and vice versa. In addition, as the types

[1] For instance, the Hong Kong government was criticized for obscuring the scale of the COVID-19 pandemic by combining suspected and confirmed infections (Ting 2022).

[2] For example, former U.S. President Trump persistently understated the risk of COVID-19 (Aleem 2020; Calvillo et al. 2020; Paz 2020). By contrast, political leaders in Europe were more inclined to highlight the severity of the pandemic (Bennhold and Eddy 2020).

[3] According to a global expert-based survey, many governments and their agents have increased their use of social media to spread misleading information in the most recent decade (Lin et al. 2022). For COVID-19 misinformation from the U.S. government, see Wikipedia (2022a), and for a list of references about government-sponsored disinformation during the COVID-19 pandemic and other epidemics such as HIV and Ebola, see Council of the European Union (2020).

become increasingly different from each other, the feasibility of a more informative equilibrium may be smaller relative to that of a less informative equilibrium. Moreover, the government need not benefit from a higher communication credibility. That is, the equilibrium social welfare under the pooling equilibrium can be higher than that under the semiseparating and/or the separating equilibrium, and socially optimal isolation can be induced under imperfect communication but not under the separating equilibrium. Nevertheless, via the use of the social welfare as a selection criterion, the separating or semiseparating equilibrium can survive as the unique outcome.

When the government weighs the public's cost of social distancing lower or somewhat higher than that of infection, the private incentive for self-isolation remains insufficient from the government's perspective. Therefore, the government's incentives for misrepresentation and the equilibrium conditions to sustain the separating equilibrium are qualitatively similar to those when the government aims to maximize social welfare. In addition, the credible-communication equilibrium can still arise when the government is overly concerned about the cost of social distancing, although the underlying challenge to ensure the government's incentive compatibility is reversed. Moreover, I find that the overall impact of an increasing emphasis on the social distancing cost on the emergence of credible communication is nonmonotonic. The communication can never (respectively, always) be credible if the relative weight the government assigns to the cost of social distancing is sufficiently low or sufficiently high (respectively, at some intermediate point).

The main model also extends to other settings. I obtain similar results when the government's private information and strategic communication is about the contagiousness of the infectious disease. Moreover, I demonstrate that my main results are robust to alternative specifications of individual heterogeneity (in the health vs. isolation cost).

This article is primarily connected to two streams of research. The first is the large literature on strategic information transmission via cheap talk (i.e., costless signaling). Originating from Crawford and Sobel (1982), this stream of research investigates the credibility of communication in various settings: matching and coordination (e.g., Bagwell and Ramey 1993), multiple information receivers (e.g., Farrell and Gibbons 1989), multidimensional private information (e.g., Chakraborty and Harbaugh 2010, 2014), search (Gardete and Guo 2021; Guo 2022b; Shin 2005), customization (Guo 2021), social preference (Kuksov, Shachar, and Wang 2013), and so on. In this article, I consider a novel setting in which the information receivers engage in a game of social distancing and endogenous infection.

I contribute to the literature on the economics of pandemic and health management, which has been rapidly growing since the outbreak of COVID-19. One important issue is how to allocate scarce medical resources (e.g., Akbarpour et al. 2021; Grigoryan 2021; Pathak et al. 2020). Guo and Xu (2022) show that more equal consumption of antipandemic resources can improve efficiency. There are empirical and computational studies on the efficacy of anticontagion policies (e.g., Acemoglu et al. 2021; Alvarez, Argente, and Lippi 2021; Atkeson 2020; Fowler et al. 2021; Hsiang et al. 2020; Webster et al. 2020; Wright et al. 2020). This article is also related to the analytical and theoretical studies on how to develop optimal policies to combat pandemics (e.g., test allocation [Ely et al. 2021], information design [De Véricourt, Gurkan, and Wang 2021], mandatory isolation [Guo 2022a]). Another broad theme is how people respond to COVID-19 (e.g., Dai and Singh 2022; De Vaan et al. 2021; Farboodi, Jarosch, and Shimer 2021; Misra, Singh, and Zhang 2022; Ru, Yang, and Zou 2021; Simonov et al. 2022).

The basic assumptions are specified in next section. In the following sections, I present the main analyses and results then the extensions. In the last section, I summarize the results, discuss the implications, and identify directions for future research. Nontrivial proofs are in the Appendix.

Setup

I consider a communication game between an information sender and a continuum of receivers who are facing the spread of an infectious disease. The information sender is a social planner (e.g., government, policy maker, public health authority). The receivers are agents whose health and well-being are influenced by the pandemic. They can represent either individuals or entities (e.g., schools, enterprises, communities). The total size of the receivers is normalized to 1. To facilitate exposition, I refer to the parties as the government and the individuals, respectively.

I focus on the parties' interaction in a given time period (e.g., day, week). When the individuals enter the period, they are "endowed" with one of two health states (i.e., $\omega \in \{0, 1\}$). The fraction of the infectious individuals ($\omega = 1$) is $p \in (0, 1)$ and that of the susceptible ones ($\omega = 0$) is $1 - p$. I assume that the individuals do not know their original health state because the development of disease symptoms (e.g., fever, coughing, fatigue, loss of taste) may take time and infection can be asymptomatic (e.g., Bai et al. 2020; Farboodi, Jarosch, and Shimer 2021; Piguillem and Shi 2022), which is an important feature of COVID-19.[4] To simplify matters, I assume that the individuals have the same belief about their original health state (i.e., each individual is infectious with probability p). That is, the belief is unbiased. I refer to p as the base infection rate, and I elaborate how it is distinguished from the effective infection probability q in the current period.

An infectious individual has been unknowingly infected. In addition, in the current period an infectious person may spread the disease to other people and a susceptible person may be newly infected. Nevertheless, as typically advised by public health authorities, social distancing measures can be adopted

[4] My results would not change even if some infectious people know their health state (e.g., due to testing, close contact, or symptomatic infection) because their social distancing behavior would be independent of the government's communication. Similarly, it is without loss of insights to ignore other possible health states (e.g., mandatorily isolated, hospitalized, immune after vaccination or recovering) in the model.

to reduce the risk of disease transmission by decreasing person-to-person interaction. For example, people can engage in self-quarantine or modify their professional and/or private activities (e.g., work from home, quit mass gatherings, delay traveling) to decrease the chance of spreading or being exposed to the virus.

Formally, each individual can decide whether to take a self-isolation action $a \in \{0, 1\}$. An individual who remains isolated ($a = 1$) does not transmit (respectively, contract) the disease if they are originally infectious (respectively, susceptible). By contrast, an infectious person who does not take the social distancing action ($a = 0$) may spread the virus to other people, and a susceptible person may risk being contaminated if they remain socially active. In particular, it is assumed that the odds of a susceptible and socially active person being infected are proportional to the fraction of infectious people who are not socially isolated (Farboodi, Jarosch, and Shimer 2021), which is denoted as x and would be derived endogenously. Taking everything together, the effective probability of an individual being initially or newly infected is

$$q(a, x) = ap + (1 - a)[p + rx(1 - p)], \tag{1}$$

where $r \in [0, 1]$ captures the expected contagiousness of the disease that is related to the basic reproduction rate in medical terminology. Note that when $a = 1$ and/or $r = 0$, we have $q = p$ (i.e., the individual would not be newly infected in the current period).

Let $\underline{u}$ and $\bar{u}$ be an individual's expected utility, depending on whether or not they contract the disease by the end of the current period, respectively.[5] Therefore, $h \equiv \bar{u} - \underline{u} > 0$ captures the expected health cost of becoming infected. It can encompass, for example, the expected costs of hospitalization, treatment, health damage, fatality, productivity loss, and so on.[6] Alternatively, social distancing can be costly as well. Let c be the cost of taking the self-isolation action $a = 1$, relative to that of choosing $a = 0$, which is normalized to 0. For instance, working from home may undermine a person's productivity and income. In addition, a self-isolated person may suffer psychologically and/or professionally from the disruption of social interaction. To account for individual difference in the isolation cost, I assume in the main model that c is heterogeneous in the population and follows the distribution $F(c)$ on the interval $[0, \bar{c}]$ with the finite density function $f(c) > 0$. Both $F(\cdot)$ and $f(\cdot)$ are continuous and differentiable. Moreover, I make the following regularity assumption and note it when it is used.

Assumption 1: $\frac{cf(c)}{1-F(c)}$ is increasing in c.

For Assumption 1 to hold, it is sufficient, but not necessary, that $1 - F(c)$ is log-concave. The class of distributions with log-concave $1 - F(\cdot)$ includes the uniform distribution, which I sometimes refer to, and many other familiar cases: the exponential, the power function, the (truncated) normal, the (truncated) logistic, the (truncated) extreme value, the modified Pareto ($F(c) = 1 - (1 - c)^{\lambda}$ for $c \in [0, 1]$ and $\lambda > 0$), and so on.

Conditional on the size of the infectious and socially active population being x, the total expected utility of an individual with the isolation cost c who takes the action a is[7]

$$\begin{aligned} u(a, x) &= [1 - q(a, x)]\bar{u} + q(a, x)\underline{u} - ac \\ &= \bar{u} - q(a, x)h - ac. \end{aligned} \tag{2}$$

In the main model, I consider the scenario in which the government is privately informed of the base infection rate, which can take two possible levels: $p \in P \equiv \{p_H, p_L\}$, where $p_H > p_L$. The common prior belief is that p is equal to p_H with probability $\theta_0 \in (0, 1)$ and equal to p_L with the complementary probability $1 - \theta_0$. I refer to the government with p_H or p_L as the high type or the low type, respectively. I also consider the alternative setting in which the government's private information, and therefore communication, is about the basic reproduction rate r.

The timing of movements is as follows. Upon privately knowing p in the first stage, the government can communicate with the public by sending a message $m \in M$ about p. I consider cheap talk (i.e., the communication per se is costless and the specific content of the message is unverifiable). It also implies that the government's message content can be freely chosen and need not be dependent on its type. In other words, the message space M can be any arbitrary set, as long as the individuals can understand the language of communication: the mapping from the government's privately informed base infection rate to the message (i.e., the communication strategy $m(p)$: $P \rightarrow M$). Thus, it is without loss of generality to consider a two-element message space in the main model: $M \equiv \{m_H, m_L\}$, where $m_H \neq m_L$.

Upon receiving the message m, the individuals would potentially update their belief about the severity of the epidemic and decide in the second stage of the game whether to socially isolate by considering their privately informed c and the expected risk of being infected. Everyone makes their social distancing decision $a \in \{0, 1\}$ independently and simultaneously with others. A person's expected utility for the current period is given by Equation 2. In the main model I focus on the case in which the government aims to maximize the society's expected welfare. I also extend the analysis to consider alternative scenarios under which the government weighs public health higher or lower relative to the expected cost of isolation across people. It is assumed that the government's objective is common knowledge.

[5] Given there are only two possible levels for the infection status, my setup can accommodate a wide range of risk attitudes to the health outcome (i.e., the individuals can be risk averse, risk neutral, or risk seeking).

[6] Note that even asymptomatic infection may lead to unforeseeable health loss in the long run.

[7] Note that $u(a, x)$ is linear in a, which implies that my results do not change even when the social distancing action is continuous (i.e., $a \in [0, 1]$). Nevertheless, to better match the reality, $a = 1$ should be interpreted as a high (vs. low) level of social distancing. After all, perfect isolation from other people can be prohibitively costly or infeasible.

In practice, there are a variety of means to distort the released number of up-to-date positive cases as a measure of the severity of a pandemic. For instance, the definition of case date and the criteria for case confirmation can be covertly manipulated. Therefore, the publicized case data need not reflect the true state of disease transmission (Pagel and Yates 2021; Starnini et al. 2021). Many countries are indeed found to deliberately make false claims about infectious diseases such as COVID-19 (e.g., Dubowitz and Ghasseminejad 2020; Lin et al. 2022; Richards 2020).

De Véricourt, Gurkan, and Wang (2021) consider a related problem on how to inform the public about a pandemic. My setup differs in two basic ways. First, De Véricourt, Gurkan, and Wang (2021) consider an environment in which no one has been previously infected but all socially active people spread the virus to each other.[8] My scenario is supposedly more reasonable and self-consistent: a person can be presymptomatically or asymptomatically infected and only the infectious, not susceptible, individuals may transmit the disease. Second and more importantly, De Véricourt, Gurkan, and Wang (2021) assume that the government commits ex ante to an information design policy about r that generates public signals, whereas I consider strategic information transmission in the sense of cheap talk about either p or r. Put differently, I relax their assumption of perfect commitment and symmetric information by allowing the government to freely misrepresent its private information.

Analysis and Results

I first examine the equilibrium self-isolation decisions conditional on people's perception about the base infection rate. This can be viewed as either a setting of symmetric information or the second stage of the model with asymmetric information. It provides the basis to derive the conditions that sustain the credibility of the government's communication about its privately informed p in a fully or partially separating equilibrium. I also compare the welfare outcomes between the different equilibria that may coexist and address the issue of equilibrium selection.

Equilibrium Social Distancing and Infection

With some abuse of notation, suppose temporarily that the individuals' perceived base infection rate is p (under either symmetric or asymmetric information). I analyze the equilibrium social distancing and its implication for endogenous infection, which may be of independent interest.

[8] That is, in contrast to Equation 1 and using my notations, the effective infection probability in De Véricourt, Gurkan, and Wang (2021) is equal to $(1 - a)rx'$, where $x' = 1 - F(\tilde{c})$ is the proportion of socially active people (see also Equation 3).

Consider an individual with isolation cost c who believes that a fraction x of people are infectious and socially active. Social distancing would be desirable $(a = 1)$ if and only if $c \leq \tilde{c} = rx(1 - p)h$. Rational expectation then implies that the public's belief about x is given by

$$x = [1 - F(\tilde{c})]p. \tag{3}$$

Therefore, the equilibrium threshold $\tilde{c}^*$ for social isolation to be optimal is determined by solving

$$\tilde{c} - r[1 - F(\tilde{c})]p(1 - p)h = 0. \tag{4}$$

> **P$_1$:** The equilibrium threshold for social distancing is unique and interior (i.e., there exists a single $\tilde{c}^* \in (0, \bar{c})$ that solves Equation 4). In addition, the equilibrium threshold $\tilde{c}^*$ increases with r and first increases then decreases with p.

In equilibrium, not all people choose to be socially isolated or active, because the probability of being infected is endogenous and a self-isolated person can exert a positive externality on others. If nobody followed social distancing guidelines, the risk of being infected would be too high, and thus those with sufficiently low isolation cost would deviate and confine themselves. Alternatively, if everybody took the self-isolation action, the incremental infection risk would be virtually 0, such that social distancing would be undesirable even for those with negligible isolation cost. Therefore, the equilibrium threshold $\tilde{c}^*$ for social distancing is interior, and people choose to be socially isolated or active according to their isolation cost.

How does the equilibrium threshold for social distancing vary with the parameters? I show that $\tilde{c}^*$ is increasing in r. Intuitively, as the basic reproduction rate increases, all else being equal, the disease would be more contagious such that more people choose to socially separate from others. A similar result can be found in De Véricourt, Gurkan, and Wang (2021), and I extend it to an alternative setting under general distribution for the isolation cost c. By contrast, the impact of the base infection rate p on the equilibrium proportion of self-isolated people is not monotonic because an increase in p can exert two countervailing effects on the incremental benefit of social distancing. On the one hand, a higher p implies that a socially active person is more likely to encounter another socially active person who is infectious (i.e., x would be higher). On the other hand, conditional on x, a higher p means that the individuals are less likely to be susceptible such that the need to be protected by social distancing would be lower. The interaction of the two forces yields an inverted U-shaped relationship between $\tilde{c}^*$ and p. When p is relatively low, the increasing-contagiousness effect would be the stronger force, because most people would be susceptible, such that $\tilde{c}^*$ is increasing in p. When p becomes sufficiently high, the lower-need-for-protection effect would dominate the contagiousness effect, because most people have been infected already, such that people are more likely to give in to the rampant epidemic as the base infection rate increases.[9]

A key assumption for P_1 is that the asymptomatic individuals make their social distancing decisions by assessing their incremental infection risk. This is the core hypothesis in Farboodi, Jarosch, and Shimer (2021, p. 26), which notes that it is commonly assumed in extant models that "individuals ramp up their social activity (or consumption and labor supply) at the moment they become sick because they have nothing left to lose." Moreover, Farboodi, Jarosch, and Shimer document empirically that people's social distancing behavior in the United States and elsewhere responded to the aggregate infection level but not to government-mandated isolation orders. In particular, it is shown that social activities were substantially reduced before stay-at-home or shelter-in-place restrictions were imposed and increased as the infection level passed its peak or remained relatively low, but before the government restrictions were lifted. These findings are consistent with the inverted U-shaped impact of the base infection rate p, as in P_1, on the equilibrium social distancing.[10]

The equilibrium aggregate infection rate can be obtained by averaging the effective infection probability q(a, x) across all people while accounting for their equilibrium behavior:

$$\begin{aligned} E[q^*] &= \int_0^{\tilde{c}^*} p\,dF(c) + \int_{\tilde{c}^*}^{\bar{c}} \{p + r[1 - F(\tilde{c}^*)]p(1-p)\}\,dF(c) \\ &= p + r[1 - F(\tilde{c}^*)]^2 p(1-p). \end{aligned} \tag{5}$$

> **P_2:** The equilibrium aggregate infection rate $E[q^*]$ first increases and then decreases with r, if and only if $\frac{\tilde{c}_1^* f(\tilde{c}_1^*)}{1-F(\tilde{c}_1^*)} > 1$, where $\tilde{c}_1^*$ is the equilibrium social distancing threshold for $r = 1$.

This proposition presents the necessary and sufficient condition on the distribution $F(\cdot)$ that leads to an inverted U-shaped relationship between the equilibrium aggregate infection rate $E[q^*]$ and the basic reproduction rate r. Interestingly, as the disease becomes more contagious, the equilibrium likelihood that a person is infected need not always be higher, because infection is endogenous in my setting, which can be influenced by r through two channels. The first channel is the direct effect: all else being equal, a higher r means an increase in the contagiousness. In addition, as shown in P_1, an increase in r induces more people to follow social distancing guidelines, thus decreasing the proportion of people who are exposed to other infectious and active people. Because of this indirect effect, the equilibrium aggregate infection rate in the whole population may decrease with the basic reproduction rate r. For example, when $F(\cdot)$ is uniform, $E[q^*]$ increases with r for $r \le \frac{\bar{c}}{p(1-p)h}$ and decreases with r for $r \ge \frac{\bar{c}}{p(1-p)h}$, where the condition in P_2 amounts to $\bar{c} < p(1-p)h$.

The result that $E[q^*]$ can be negatively affected by r has significant implications for practice and academic research. It is standard to compute the ratio of the number of positive cases (during a specific period) to the population size as a measure of the infection probability. This ratio is usually termed the "infection rate," akin to p or $E[q^*]$ (before or during current period) in my setting, and commonly used for comparison across time, regions, and/or diseases (Wikipedia 2022b). However, I show that this empirical infection rate need not reflect the intertemporal trend, cross-sectional difference, or actual transmissibility of infectious diseases. That is, the frequency of positive cases may not capture, but can be negatively related to, a disease's underlying contagiousness. The confounding factor I highlight is that people may respond to an increasing infection risk by taking preventive actions (e.g., social distancing). As a result, the public may be less likely to contract a virus that is easier to spread and vice versa. Moreover, my result suggests that when the disease becomes rampant enough (i.e., r is sufficiently high), the endogeneity is more likely to lead to a negative relationship between the empirical infection rate and the actual contagiousness.

Equilibrium Communication Under Asymmetric Information

I turn to my main interest in the credibility of the government's strategic communication about its privately informed base infection rate p. The solution concept I use is the perfect Bayesian equilibrium. It stipulates that the public's belief about the government's type is consistent with the government's equilibrium communication strategy m(p), and that all parties make optimal decisions conditional on their own belief and the other parties' optimal behavior.

First, note that, as in any cheap talk model, there is always an equilibrium in which the government's message is uninformative and the public's belief about the government's type remains unchanged from the prior θ_0. Under this babbling (pooling) equilibrium, the individuals' self-isolation behavior and the aggregate infection rate can be similarly characterized as in the previous section by replacing p with its prior mean $\theta_0 p_H + (1 - \theta_0)p_L$.

My focus is on investigating the extent to which the government's privately known p can be credibly conveyed to the public. I identify the conditions under which the government types can be fully or partially separated in equilibrium.

Fully informative communication. Consider the pure strategy equilibrium in which the government types are fully revealed. Under the separating equilibrium, the government's communication strategy is $m(p_H) = m_H$ and $m(p_L) = m_L$. The perfect Bayesian equilibrium requires that upon receiving

[9] In practice, a high infection level may not be reached for a specific pandemic. Therefore, the negative relationship I predict between the equilibrium social distancing behavior and the base infection rate may not be frequently or easily observed.

[10] Similarly, social activities can be influenced by other factors that change people's perceived infection risk. For example, anticipation of COVID-19 vaccines (Andersson et al. 2021) or uptakes (Guo, Lu, and Wei 2022) can reduce people's willingness to comply with public health guidelines such as voluntary social distancing.

m, the public's updated belief be $\hat{p}(m_H) = p_H$ and $\hat{p}(m_L) = p_L$. To derive the conditions under which the separating equilibrium can be sustained, I need to define the government's expected payoff, conditional on its actual type p and the perceived type $\hat{p}$. To this end, I make the following definition on the expected utility across all people (i.e., the social welfare), for a given p and a particular social distancing threshold $\tilde{c}$:

$$SW(p, \tilde{c}) = \tilde{u} - \int_0^{\tilde{c}} (ph + c)dF(c) - \int_{\tilde{c}}^{\bar{c}} \{p + r[1 - F(\tilde{c})]p(1 - p)hdF(c)\}$$
$$= \tilde{u} - ph - \int_0^{\tilde{c}} cdF(c) - r[1 - F(\tilde{c})]^2 p(1 - p)h. \quad (6)$$

The equilibrium self-isolation threshold in response to a perceived $\hat{p}$ is $\tilde{c}^*(\hat{p})$ that solves Equation 4. Therefore, given that the government maximizes the social welfare, its expected payoff function would be $SW(p, \tilde{c}^*(\hat{p}))$ when its true type is p and the public believes it is of type $\hat{p}$.

For the cheap talk to be credible, the government must prefer to reveal its type truthfully, given that its self-reported type would be believed by the public. That is, the communication strategy $m(p_i) = m_i$ must be optimal, given that the public's belief updating is $\hat{p}(m_i) = p_i, i \in \{H, L\}$. This yields the following incentive compatibility (IC) conditions:

$$IC_H: SW(p_H, \tilde{c}^*(p_H)) \geq SW(p_H, \tilde{c}^*(p_L)), \quad (7)$$

$$IC_L: SW(p_L, \tilde{c}^*(p_L)) \geq SW(p_L, \tilde{c}^*(p_H)). \quad (8)$$

To facilitate the equilibrium characterization, I define $\rho \equiv p(1 - p)$ and call it the "incremental infection rate." It captures the likelihood that among socially active people, a person is initially susceptible but meets another infectious person. Accordingly, for a given $\rho \in \{\rho_H, \rho_L\}$ and a social distancing threshold $\tilde{c}$, I define the "aggregate incremental cost" as

$$C(\rho, \tilde{c}) = \int_0^{\tilde{c}} cdF(c) + \int_{\tilde{c}}^{\bar{c}} r[1 - F(\tilde{c})]\rho hdF(c)$$
$$= \int_0^{\tilde{c}} cdF(c) + r[1 - F(\tilde{c})]^2 \rho h. \quad (9)$$

Similar to Equation 4, the public's equilibrium self-isolation threshold in response to a perceived $\hat{\rho}$ is given by $\tilde{c}^*(\hat{\rho})$ (with some abuse of notation) that solves

$$\tilde{c} - r[1 - F(\tilde{c})]\hat{\rho}h = 0. \quad (10)$$

Note that the government's expected payoff function can be rewritten as $SW(p, \tilde{c}^*(\hat{\rho})) = \bar{u} - ph - C(\rho, \tilde{c}^*(\hat{\rho}))$. Therefore, the IC constraints in Equations 7 and 8 can be equivalently represented as

$$IC_H^C: C(\rho_H, \tilde{c}^*(\rho_H)) \leq C(\rho_H, \tilde{c}^*(\rho_L)), \quad (11)$$

$$IC_L^C: C(\rho_L, \tilde{c}^*(\rho_L)) \leq C(\rho_L, \tilde{c}^*(\rho_H)). \quad (12)$$

Lemma 1: A separating equilibrium of credible communication can arise if and only if either of the two conditions is satisfied: (1) $\rho_L < \rho_H$ and $\rho_L \leq \rho_1(\rho_H)$ or (2) $\rho_H < \rho_L$ and $\rho_H \leq \rho_1(\rho_L)$, where $\rho_1(\cdot)$ is an increasing function.

To illustrate the conditions to sustain the credible-communication equilibrium, I focus on the case $\rho_L < \rho_H$; the low base infection rate p_L is associated with a lower incremental infection rate ρ_L. The alternative case $\rho_H < \rho_L$ is analogous. Note that the social distancing threshold $\tilde{c}^{**}(\rho)$ that minimizes the aggregate incremental cost $C(\rho, \tilde{c})$ is the unique and interior solution to

$$\tilde{c} - 2r[1 - F(\tilde{c})]\rho h = 0. \quad (13)$$

In comparison with Equation 10, it follows that the equilibrium self-isolation (if the true type is correctly perceived) is insufficient relative to the efficient level, $\tilde{c}^*(\rho) < \tilde{c}^{**}(\rho)$ for all ρ, because the individuals fail to internalize the spillover effect of their isolation in reducing the infection risk for other people. Moreover, as shown in the Appendix, $C(\rho, \tilde{c})$ is quasiconvex in $\tilde{c}$ such that the government would have no incentive for deceptive communication if that induces people to choose a lower equilibrium self-isolation threshold $\tilde{c}^*$. As a result, given that the individuals' equilibrium self-isolation $\tilde{c}^*(\hat{\rho})$ is increasing in the perceived $\hat{\rho}$, the government with ρ_H would not misrepresent its type at all; the IC_H^C constraint is always satisfied.

Nevertheless, the IC_L^C constraint may be violated: the government with ρ_L may have an incentive to deceive the public to believe that it is the ρ_H type in order to raise the level of social distancing closer to the efficient level $\tilde{c}^{**}(\rho_L)$. However, miscommunication may backfire and lead to excessive social distancing. As shown in Lemma 1, this would happen if and only if the value of ρ_L is sufficiently small relative to ρ_H. It is because the actual incremental infection risk at such a ρ_L would be too low such that the government would prefer more people to remain socially active, relative to what they would do if they are misled to believe that the incremental infection rate is as high as ρ_H. Therefore, if and only if ρ_L is lower than some threshold $\rho_1(\rho_H)$, the credibility in the government's communication can be sustained. Moreover, I show that this threshold would be raised as ρ_H increases. When the distribution of the isolation cost c is uniform, the threshold for truthful communication would be given by $\rho_1(\rho_H) = \frac{\sqrt{9\bar{c}^2 + 8r\rho_H h\bar{c}} - 3\bar{c}}{4rh}$.

The incentive of the government (of the ρ_L type) to communicate deceptively or truthfully is illustrated in Figure 1, Panel A, where the curves represent the aggregate incremental cost $C(\rho_L, \tilde{c})$ as a function of the social distancing threshold $\tilde{c}$. I present two scenarios, each for a different ρ_L (i.e., $\rho_{L1} < \rho_{L2}$). The dashed curve captures the scenario of ρ_{L2} that is not too low, whereby deviating to claim to be the ρ_H type would reduce the aggregate incremental cost: $C(\rho_{L2}, \tilde{c}^*(\rho_{L2})) > C(\rho_{L2}, \tilde{c}^*(\rho_H))$. By contrast, when ρ_L is reduced to ρ_{L1} (the solid curve), truthfully revealing it would generate a higher social welfare than imitating

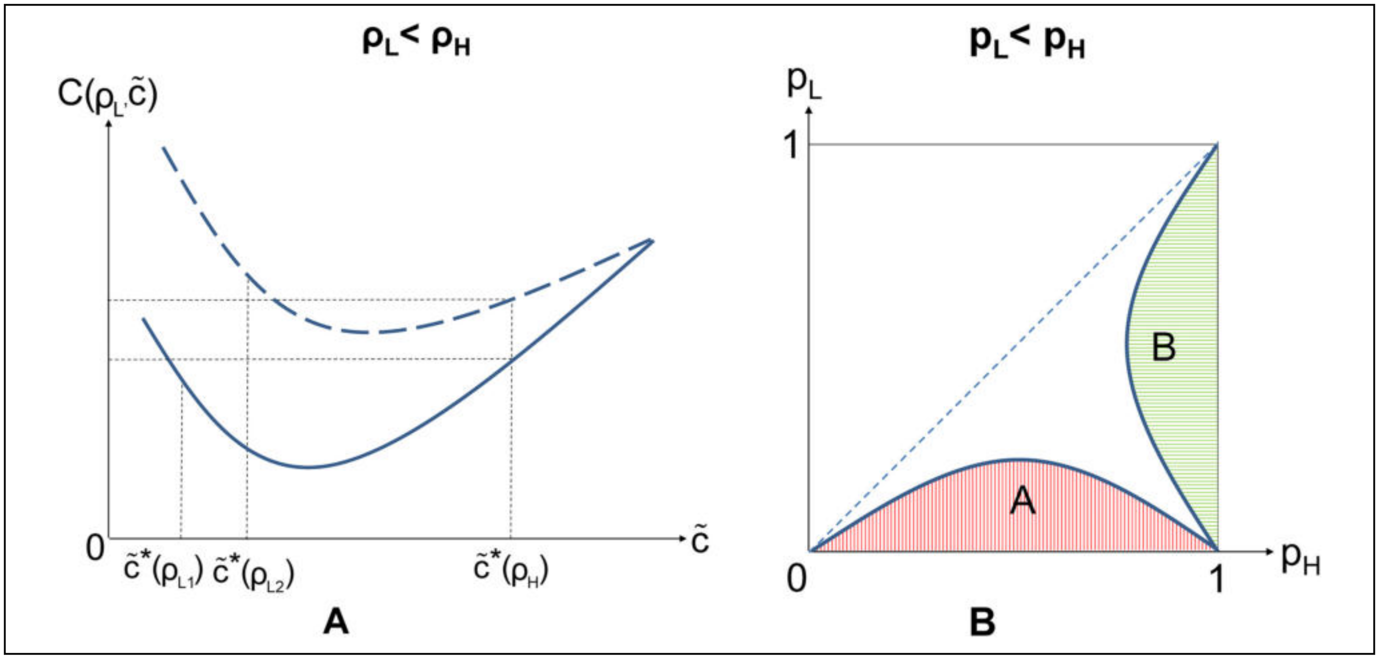

Figure 1. Incentive Compatibility for Credible Communication (Separating Equilibrium).

the ρ_H type: $C(\rho_{L1}, \tilde{c}^*(\rho_{L1})) < C(\rho_{L1}, \tilde{c}^*(\rho_H))$. Thus, credible communication can be sustained for ρ_{L1} but not for ρ_{L2}.

Substituting $\rho = p(1 - p)$ into Lemma 1, I can readily obtain the following result.

P_3: A separating equilibrium of credible communication can arise if and only if $p_L \le \frac{1-\sqrt{1-4\rho_1(p_H(1-p_H))}}{2}$ or $p_H \ge \frac{1+\sqrt{1-4\rho_1(p_L(1-p_L))}}{2}$.

This proposition presents the necessary and sufficient conditions for the separating equilibrium of informative communication to emerge, in terms of the base infection rates which are my model primitives. The communication can be credible under two circumstances. The first is illustrated by Figure 1, Panel B, Region A, where the low base infection rate p_L is sufficiently low such that the implied incremental infection rate is also lower than that of the countertype (i.e., $\rho_L < \rho_H$). Intuitively, equilibrium separation can be achieved if there is sufficient heterogeneity between the types. Nevertheless, the highest p_L that can sustain the credibility first increases and then decreases with p_H. It implies that for a given p_L, an increasing p_H need not always enhance the chance to observe the separating equilibrium. This is because a person's incentive for social isolation can be affected by an increase in the base infection rate in two countervailing ways. Consequently, recall from P_1 that the equilibrium social distancing threshold $\tilde{c}^*$ varies with p in an inverted U-shaped fashion. This nonmonotonic incentive yields the nonmonotonic pattern in Region A.

The second circumstance on the emergence of the separating equilibrium is when the high base infection rate p_H becomes sufficiently high such that its associated incremental infection rate becomes lower than that of the low type (i.e., $\rho_H < \rho_L$) (recall that $\rho = p(1 - p)$). As illustrated by Figure 1, Panel B, Region B, credible communication can arise in this case if the low base infection rate p_L is intermediate. Similar to the other scenario (Region A), a sufficiently high p_H and an intermediate p_L implies that the two types are different enough in terms of their incremental infection rates. Nevertheless, the two types' incentives for miscommunication are reversed: it is now the high type that may desire to be perceived as the low type to induce more social distancing. In addition, analogously, the lowest p_H that can yield credible communication first decreases and then increases with p_L. It implies that the likelihood of observing the separating equilibrium may be raised, rather than diminished, as p_L becomes closer to p_H. This is again because the public's incentive for self-isolation is related to the base infection rate in an inverted U-shaped manner.

I summarize the conditions on the credible-communication equilibrium. There must be some difference between the base infection rates, which need not be large especially when p_H and p_L are both low or high (see Figure 1, Panel B).[11] Nevertheless, interestingly, an increasing difference between the types may facilitate or impede the credibility of communication by influencing the government's incentive to exaggerate (Region A) or understate (Region B) its true type.

[11] In practice the range of possible infection rates may not be very wide, because people can gain partial information from other credible sources to reduce their uncertainty. This can be readily accommodated in my setup by restricting the difference between p_H and p_L, which would not qualitatively change my results.

Partially informative communication. Next, I consider semiseparating equilibrium in which communication is partially informative. That is, I examine whether and when the government of one type truthfully communicates its private information and the other type randomizes between m_H and m_L. To this end, let the individuals' expected base infection rate be $p_\theta \equiv \theta p_H + (1-\theta)p_L$ and the expected incremental infection rate be $\rho_\theta \equiv p_\theta(1-p_\theta)$ when their post-communication belief is that the government's true type is p_H with probability $\theta \in (0, 1)$ and p_L with probability $1-\theta$.

For example, consider the case $\rho_L < \rho_H$ (the alternative case $\rho_H < \rho_L$ is analogous). As I show in the Appendix, there does not exist a semiseparating equilibrium in which the ρ_L-type government communicates truthfully and the ρ_H-type government engages in random communication. Nevertheless, the other type of semiseparating equilibrium may emerge, in which the government with ρ_H strictly prefers to reveal its type, whereas the ρ_L type is indifferent between separating from and pooling with the high type. Intuitively, this is because $\frac{\partial^2 C(\rho, \tilde{\varepsilon}^*(\hat{\rho}))}{\partial\hat{\rho}\partial\rho} < 0$ such that, relatively speaking, the government is more inclined to induce a higher perception $\hat{\rho}$ on the incremental infection rate when its true type involves a higher versus lower incremental infection rate ρ.

P_4: There exists a semiseparating equilibrium in which the high type communicates truthfully and the low type randomizes between m_H and m_L if and only if $p_L < \frac{1-\sqrt{1-4\rho_1(1/4)}}{2}$ and: (1) $\frac{1-\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2} < p_H < \frac{1+\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2}$ and $p_H < \frac{1-2(1-\theta_0)p_L-\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2\theta_0}$ or (1′) $p_H > \frac{1+\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2}$, $p_H < 1-p_L$, and $p_H < \frac{1-2(1-\theta_0)p_L+\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2\theta_0}$.

There exists a semiseparating equilibrium in which the low-type government communicates truthfully and the high type randomizes between m_H and m_L if and only if $p_H > \frac{1+\sqrt{1-4\rho_1(1/4)}}{2}$ and: (2) $\frac{1-\sqrt{1-4\rho_1^{-1}(p_H(1-p_H))}}{2} < p_L < \frac{1+\sqrt{1-4\rho_1^{-1}(p_H(1-p_H))}}{2}$ and $p_L > \frac{1-2\theta_0 p_H+\sqrt{1-4\rho_1^{-1}(p_H(1-p_H))}}{2(1-\theta_0)}$ or (2′) $p_L < \frac{1-\sqrt{1-4\rho_1^{-1}(p_H(1-p_H))}}{2}$, $p_L > 1-p_H$, and $p_L > \frac{1-2\theta_0 p_H-\sqrt{1-4\rho_1^{-1}(p_H(1-p_H))}}{2(1-\theta_0)}$.

I identify the full set of necessary and sufficient conditions under which the high type or the low type, but not both, mixes between reporting truthfully and falsely in equilibrium. These conditions are illustrated in Figure 2, along with those for the other equilibria, in the space of the base infection rates (p_H and p_L). I obtain several findings. First, the semiseparating equilibrium can coexist with the pooling and the separating equilibria. This is characterized in P_4, Scenarios 1 and 2 and illustrated by Figure 2, Regions A_1 and B_1 for the low-type or the high-type mixing equilibrium, respectively. Second, the semiseparating equilibrium can emerge even when the separating equilibrium does not exist. In particular, under the parameter values given in P_4, Scenario 1′, which is captured by Figure 2, Region A_2, the two types cannot be completely separated, but as the low type mimics the high type the public's perceived incremental infection rate ρ_θ can be raised (and higher than ρ_H) such that the low type's incentive for separation would be enhanced to the extent to sustain the semiseparating equilibrium. Similar situations can also happen in Scenario 2′ and Region A_2, where the equilibrium communication can involve partial, but not full, separation and mixing for the high type. Third, there are circumstances under which the separating equilibrium can be supported but the semiseparating equilibrium cannot. That is, either region (A or B) may contain a nonempty subset under which the government types would be separated or pooled together in equilibrium. Fourth, when p_H and p_L are sufficiently close in the remaining parameter space, the pooling equilibrium would be unique and the communication cannot be informative at all.

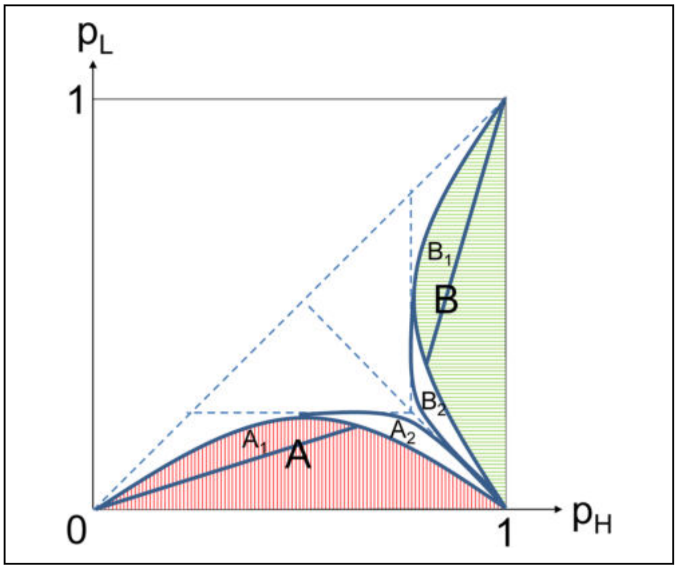

Figure 2. Existence Conditions for Semiseparating and Separating Equilibria.

I can readily verify that the parameter space for the low-type mixing equilibrium (Regions A_1 and A_2) would shrink as θ_0 increases. Intuitively, it is because it would be harder for the low-type government to manipulate the public's perception on the incremental infection rate by mingling with the high type. Conversely, a higher θ_0 would expand the set of parameter values for the semiseparating equilibrium with the high-type mixing (Regions B_1 and B_2). The mechanism is analogous: the scope of perception manipulation would be enhanced for the high type to pretend to be the low type as the prior likelihood for the low type decreases.

As Figure 2 illustrates, when the difference between the two types increases (higher p_H or lower p_L), we may move from the separating to the semiseparating equilibrium (from Region A to A_2 or B to B_2). In addition, a larger difference between the types may reduce the feasibility of the semiseparating equilibrium while rendering the pooling equilibrium the unique outcome.

Table 1. Comparing Equilibrium Social Welfare.

Parameter Region (Figure 2)	Equilibrium	Low–Type Social Welfare	High–Type Social Welfare
A_1	Pooling, low-type mixing, separating	$\mathbf{SW_L^0} > SW_L^1 = SW_L^2$	$SW_H^0 < SW_H^1 < SW_H^2$
$A\backslash A_1$	Pooling, separating	$SW_L^0 < SW_L^2$	$\mathbf{SW_H^0} \lesssim SW_H^2$
A_2	Pooling, low-type mixing	$\mathbf{SW_L^0} \gtrsim SW_L^1$	$\mathbf{SW_H^0} \lesssim \mathbf{SW_H^1}$
B_1	Pooling, high-type mixing, separating	$SW_L^0 < SW_L^1 < SW_L^2$	$\mathbf{SW_H^0} > SW_H^1 = SW_H^2$
$B\backslash B_1$	Pooling, separating	$\mathbf{SW_L^0} \lesssim SW_L^2$	$SW_H^0 < SW_H^2$
B_2	Pooling, high-type mixing	$\mathbf{SW_L^0} \lesssim \mathbf{SW_L^1}$	$\mathbf{SW_H^0} \gtrsim SW_H^1$

Notes: The social welfare for type i = H, L under the equilibrium j = 0 (pooling), 1 (semiseparating), 2 (separating) is denoted by SW_i^j. A bolded entry indicates that the social welfare under that equilibrium can reach the socially optimal level for the given type.

Therefore, the equilibrium communication need not be more informative as the types become increasingly different. This comparative static result reinforces the finding in the previous subsection on the scope of the separating (vs. pooling) equilibrium.

Welfare Implications of Communication Credibility

How would the credibility of communication influence the government's equilibrium expected payoff? To address this issue, I compare the social welfare for each government type between the equilibria that involve different levels of communication credibility and coexist under the same set of parameter values. This comparison enables me to capture the endogenous impact of communication credibility while controlling for variations in the exogenous parameters. In particular, I denote the social welfare for type $i \in \{H, L\}$ as SW_i^j, where the superscript $j \in \{0, 1, 2\}$ represents the equilibrium number of types that would communicate faithfully (i.e., the pooling, semiseparating, and separating equilibrium, respectively). The cross-equilibrium comparison on the social welfare is summarized in Table 1, which is analogous across the $\rho_L < \rho_H$ (A_1, $A\backslash A_1$, A_2) and the $\rho_H < \rho_L$ (B_1, $B\backslash B_1$, B_2) cases by switching the role of the two types. As I show in the Appendix, as the level of communication credibility increases across the different equilibria, the public's perception $\hat{\rho}$ on the incremental infection rate and therefore the expected social distancing threshold $\tilde{c}^*(\hat{\rho})$ would be modified to affect the aggregate incremental cost $C(\rho, \tilde{c}^*(\hat{\rho}))$ and the social welfare.

There are several points to highlight from Table 1. First, the government need not benefit from a higher communication credibility. The social welfare under the pooling equilibrium can be higher than that under the semiseparating and/or the separating equilibrium. This can be the case for the type with the relatively lower or the relatively higher ρ, because pooling can yield a higher incremental infection rate $\hat{\rho}$, in comparison with both ρ_L and ρ_H, to raise the expected social distancing threshold $\tilde{c}^*(\hat{\rho})$. Second, as indicated by the bolded cases in Table 1, the maximum possible social welfare can arise for either type (nonconcurrent) and under the pooling or the semi-separating equilibrium. This is also because imperfect (and biased) communication may restore the expected social distancing threshold $\tilde{c}^*(\hat{\rho})$ to reach the socially optimal level $\tilde{c}^{**}(\rho)$.

Third, the two types may agree on which equilibrium would yield a higher social welfare. Therefore, I can use the social welfare as a criterion for equilibrium selection. In particular, as shown in the Appendix, the separating equilibrium in Region $A\backslash A_1$ or $B\backslash B_1$ can be selected by the welfare criterion if $\rho_{\theta_0} < \rho_H$ or $\rho_{\theta_0} < \rho_L$, respectively. In addition, either the pooling or the semiseparating equilibrium in Region A_2 or B_2 can yield a higher social welfare for both types. For instance, if ρ_{θ_0} is sufficiently higher than ρ_θ, the welfare criterion can be used to select the semiseparating equilibrium in Region A_2 or B_2. These results demonstrate that credible communication can survive as the unique equilibrium outcome even under the cheap talk setting.

Extensions

I extend the main model along several directions and perform additional analyses. I examine the robustness of the main results and generate new insights.

Unequal Balance Between Health and Isolation Costs

I generalize my setting to consider uneven weights between the health and isolation costs. Some social planners may weigh the population's health disproportionately higher. Conversely, the economy and/or the negative consequences of social distancing may be the government's priority over public health. There can also be other political, ideological, religious, and/or short- versus long-term considerations in trading off the health and isolation costs. To reflect these alternative scenarios, I consider the following generalization to the aggregate incremental cost:

$$C_\alpha(\rho, \tilde{c}) = \alpha \int_0^{\tilde{c}} c dF(c) + \int_{\tilde{c}}^{\bar{c}} r[1 - F(\tilde{c})]\rho h dF(c) = \alpha \int_0^{\tilde{c}} c dF(c) + r[1 - F(\tilde{c})]^2 \rho h, \quad (14)$$

where $\alpha > 0$ is the relative weight the government assigns to the consideration of the isolation cost (e.g., the economy). Public health is weighed more when $\alpha < 1$, whereas the government is biased toward the cost of social distancing when $\alpha > 1$.

The government's objective is to minimize $C_\alpha(\rho, \tilde{c}^*(\hat{\rho}))$ by considering the potential impact of its communication on the public's perceived $\hat{\rho}$. The IC constraints to sustain the separating equilibrium can then be similarly defined as those in Equations 11 and 12.

Lemma 2: A separating equilibrium of credible communication can arise under the general setting of unequal weights if and only if either of the two conditions is satisfied: (1) $\rho_L < \rho_H$ and $\rho_L \leq \rho_\alpha(\rho_H)$ or (2) $\rho_H < \rho_L$ and $\rho_H \leq \rho_\alpha(\rho_L)$, where $\rho_\alpha(\cdot)$ is an increasing function and is increasing in α for $\alpha \leq 2$ but decreasing in α for $\alpha \geq 2$.

I generalize the results in the main model (Lemma 1). When the relative weight the government assigns to the isolation cost is not overly high ($\alpha < 2$), social separation chosen by the public under symmetric information remains insufficient for the government, because the individuals do not internalize the impact of their behavior on other people's infection risk. That is, $\tilde{c}^*(\rho) < \tilde{c}^{**}_\alpha(\rho)$ for all ρ, which would be the case even if the government cares somewhat more about the social distancing cost than public health (i.e., $\alpha \in (1, 2)$). Therefore, the government with a low ρ may have an incentive to mimic the other type to restore the public's investment in social distancing, but not vice versa for the type with high ρ. Nevertheless, as in the main model (e.g., Figure 1, Panel A), such deceptive communication would not be appealing if and only if, for example, the low ρ_L is lower than some threshold $\rho_\alpha(\rho_H)$ that continues to be an increasing function of ρ_H.

I also show that a higher α in this range would raise the threshold $\rho_\alpha(\cdot)$ for the emergence of credible communication. Intuitively, as the government becomes more concerned about the isolation cost, its preferred level of social distancing would go down and closer to that chosen by the public. As a result, there would be less need for deception, and communication is more likely to be credible. Actually, when $\alpha = 2$, the social and the private preferences for isolation would match perfectly (i.e., $\tilde{c}^*(\rho) = \tilde{c}^{**}_2(\rho)$) such that both types would choose to convey their private information truthfully for any (ρ_H, ρ_L). This stands in contrast to the extreme scenario in which the government does not care about the isolation cost at all ($\alpha \to 0$); $\rho_\alpha(\cdot)$ would converge to 0 and credible communication would be impossible for any parameter.

The coin would flip when the government weighs the isolation cost sufficiently higher than the health cost ($\alpha > 2$). The government would prefer more people to be socially active than what they would choose to be, despite their failure to consider their behavior's externality; $\tilde{c}^*(\rho)$ would be higher than $\tilde{c}^{**}_\alpha(\rho)$ for any ρ. As a result, it is now the high-ρ government, but not the low-ρ type, that may mimic the other type to discourage social distancing. That is, the government may have an incentive to understate the incremental infection rate, but not the opposite. Excessive understatement may not be desirable though. Therefore, analogously, the government may avoid deceptive communication if the low ρ is lower than some threshold $\rho_\alpha(\cdot)$. However, the threshold $\rho_\alpha(\cdot)$ is not qualitatively symmetric around $\alpha = 2$. When $\alpha > 2$, it is still an increasing function when $F(\cdot)$ is uniform, but it may no longer be monotonic for other distributions. In addition, it may equal 0 if α becomes too high. In other words, it is possible that the credible-communication equilibrium cannot be sustained even if the low ρ converges to 0.

Moreover, the impact of α on the threshold $\rho_\alpha(\cdot)$ is qualitatively reversed for the range $\alpha > 2$. As the government's concern about the isolation cost increases, its preferred level of social distancing would decrease and become increasingly different from that selected by the public. As a result, the high-ρ government would be more willing to downplay the incremental infection rate by pretending to be the low-ρ type. This implies that the credibility of communication would be harder to establish. Actually, when α becomes sufficiently high, for any (ρ_H, ρ_L), the equilibrium communication cannot be informative. This can happen even for a finite α.

P_5: A separating equilibrium of credible communication can arise under the general setting of unequal weights if and only if $p_L \leq \frac{1-\sqrt{1-4\rho_\alpha(p_H(1-p_H))}}{2}$ or $p_H \geq \frac{1+\sqrt{1-4\rho_\alpha(p_L(1-p_L))}}{2}$.

The necessary and sufficient conditions for the separating equilibrium, on the space of the base infection rates, follow readily from the results in Lemma 2. There are two observations to note. First, the basic structure of the conditions is qualitatively similar to that in the main model. When the government does not overweigh the isolation cost a lot ($\alpha < 2$), as in Figure 1, Panel B, the conditions are represented by two regions (A and B), capturing the scenarios when p_L is sufficiently low (i.e., low ρ_L) or p_H is sufficiently high (i.e., low ρ_H), respectively. The challenge in these two scenarios is to ensure that the government does not exaggerate the low p_L or does not downplay the high p_H, respectively. When the relative weight placed on the isolation cost is overly high ($\alpha > 2$), there are still two kinds of scenarios for credible communication to emerge, which are akin to Figure 1, Panel B, Regions A and B. However, each of them may be broken into some disconnected subsets because the function $\rho_\alpha(\cdot)$, as characterized in Lemma 2, may not be monotonic anymore. Another difference is that the critical challenges that may collapse the separating equilibrium are reversed from those when $\alpha < 2$; it is now the understatement of the high p_H in Region A and the inflation of the low p_L in Region B. Nevertheless, for any α, the property is still reserved that an increasing difference between the types may either expand or shrink the required parameter space.

Second, a greater emphasis on the isolation cost influences the emergence of the separating equilibrium in a nonmonotonic way. As α increases toward 2, both regions (A and B) in Figure 1, Panel B, would expand. When $\alpha = 2$, the communication would be credible in equilibrium for the whole space of (p_H, p_L) under the 45-degree line. However, as α further increases and moves away from 2, the parameter space for the separating equilibrium would decrease. It would finally become an empty set when α becomes too high.

I am ready to discuss how the main results in De Véricourt, Gurkan, and Wang (2021) regarding the equilibrium information transmission would be modified, as their commitment assumption is relaxed in my setting of cheap talk. First, De Véricourt, Gurkan, and Wang show that when the government aims to maximize social welfare, it always commits to disclose the information fully (for both states). However, as I show in P_3, full disclosure may be unsustainable if commitment is infeasible. In addition, as demonstrated in P_4, there may exist semiseparating equilibrium in which the government partially distorts its private information (i.e., exaggerates p_L or downplays p_H). Second, depending on the health cost, the optimal information policy in De Véricourt, Gurkan, and Wang's setting may involve full disclosure, exaggeration (respectively, understatement), or full concealment when the government cares only about public health (respectively, only about the isolation cost). This stands in contrast to my finding that when α converges to 0 or becomes sufficiently high, credible communication can no longer happen in equilibrium (for any parameter).

Communication About Disease Contagiousness

In the main model, I focus on the communication about the base infection rate p. It does not necessarily mean that the individuals are fully informed of other measures about the pandemic's severity or contagiousness. Instead I intend to capture the situation that social planners' comparative information advantage over the public is typically larger for empirical measures, such as the base infection rate p, than for other latent measures, such as the basic reproduction rate r. Estimating r promptly and accurately is usually hard, even for public health authorities. Making inference about it from observables can also be problematic, especially in light of my finding in P_2 that its influence on the aggregate infection rate $E[q^*]$ can be nonmonotonic. Therefore, r in my main model should be interpreted as the expected basic reproduction rate, where its true value is unknown to both the government and the individuals.

Nevertheless, I next consider the alternative scenario in which the government is privately informed of the basic reproduction rate r and p is common knowledge. The common prior belief is that r is equal to either r_H or r_L with probability $\pi_0 \in (0, 1)$ or $1 - \pi_0$, respectively, where $r_L < r_H$.[12] Other aspects of the game are as in the main model, except the government's communication is about r.

As in Equation 9, conditional on the social distancing threshold $\tilde{c}$, the aggregate incremental cost for the government type r is

$$C(r, \tilde{c}) = \int_0^{\tilde{c}} c dF(c) + r[1 - F(\tilde{c})]^2 \rho h. \quad (15)$$

Similar to the main model, $C(r, \tilde{c})$ is quasiconvex in $\tilde{c}$, and the sorting condition $\frac{\partial^2 C(r, \tilde{c})}{\partial \tilde{c} \partial r} < 0$ continues to hold. The social distancing threshold that minimizes $C(r, \tilde{c})$, $\tilde{c}^{**}(r)$, is still the unique and interior solution to Equation 13, and the equilibrium social distancing threshold (under symmetric information), $\tilde{c}^*(r)$, can be similarly obtained from Equation 4 or 10 as a unique and interior solution. In addition, it is evident that $\tilde{c}^{**}(r) > \tilde{c}^*(r)$ for all r and both functions are increasing in r. These properties are analogous to those for ρ simply because these two parameters are fully exchangeable in my setting. Therefore, I can obtain similar results as in the main model. That is, a separating equilibrium of credible communication can arise if and only if $r_L \le \rho_1(r_H)$, where $\rho_1(\cdot)$ is the same as in Lemma 1.

Heterogeneity in the Health Cost

In the main mode, I assume the individuals are homogenous in the health cost. This can happen if, when the individuals make their social distancing decisions, they cannot precisely foresee the potential consequences of being infected and therefore cannot generate individual-specific estimates of the health cost. Nevertheless, I next investigate the alternative case of heterogeneous health cost while taking the self-isolation cost $c > 0$ to be homogenous to facilitate tractability. Let the distribution of the health cost h be G(h) on the interval $[\underline{h}, \bar{h}]$, where $\underline{h}$ is nonnegative and $\bar{h}$ is sufficiently high (potentially unbounded). Both $G(\cdot)$ and the finite density $g(\cdot) > 0$ are continuous and differentiable functions. I note the following regularity assumption when it is used.

Assumption 2: $\frac{hg(h)}{G(h)}$ is decreasing in h.

It should be noted that this is a stronger assumption than G(h) being log-concave. Nevertheless, it can be satisfied for many distributions (e.g., the exponential, the power function, the Pareto).

The analysis and results are similar to those in the main model (for the major proofs, see the Appendix). An individual would choose to be socially active ($a = 0$) if and only if $h \le \tilde{h} = \frac{c}{rx(1-p)}$. It follows that the public's belief about the proportion of infectious and socially active people is $x = G(\tilde{h})p$. Taken together, I can then obtain the equilibrium threshold $\tilde{h}^*$

[12] I also consider an alternative setup of continuous support for the state space (in the communication about either p or r). As in Crawford and Sobel (1982), any equilibrium is a partition equilibrium in which the government divides the state space into $n \ge 1$ intervals and reveals to the public which interval contains the true state. Nevertheless, one notable difference is that the upper bound on the number of feasible partitions is not less than 2, which need not be true in the general setting of Crawford and Sobel. In other words, there exists at least one partially informative equilibrium, even without further specialization to my model. Intuitively, it is because the conflict of interest in my setting between the government and the individuals is endogenous and can converge to 0 when the value of the state is sufficiently small (i.e., the incentive for misrepresentation can be locally missing). Moreover, in the communication game about p that is continuously distributed, I would generate similar nonmonotonic patterns as in the binary case of the main model. For example, the equilibrium credibility or informativeness of the communication can go up or down as p increases, analogous to Figure 1, Panel B, and Figure 2.

for social activity as the solution to

$$\mathrm{r}\rho(1-\mathrm{p})\mathrm{G}(\tilde{\mathrm{h}})\tilde{\mathrm{h}}-\mathrm{c}=0. \tag{16}$$

Analogous to P_1, I show that the equilibrium threshold $\tilde{h}^*$ is unique and interior, decreases with r, and first decreases and then increases with p.

In comparison with Equation 5, the equilibrium aggregate infection rate becomes

$$\begin{aligned}\mathrm{E}[\mathrm{q}^*] &= \int_{\underline{h}}^{\tilde{h}^*}[p+rp(1-p)G(\tilde{h}^*)]dG(h)+\int_{\tilde{h}^*}^{\bar{h}}pdG(h)\\ &= p+rp(1-p)G(\tilde{h}^*)^2. \end{aligned}\tag{17}$$

I demonstrate that, similar to P_2, $E[q^*]$ is concave in r, and there is $G(\cdot)$ such that $E[q^*]$ first increases and then decreases with r, such that $E[q^*]$ always decreases with r.

Analogous to Equation 9, conditional on the incremental infection rate $\rho \in \{\rho_H, \rho_L\}$ and the social activity threshold $\tilde{h}$, the aggregate incremental cost becomes

$$H(\rho, \tilde{h}) = \int_{\underline{h}}^{\tilde{h}} r\rho G(\tilde{h})hdG(h) + \int_{\tilde{h}}^{\bar{h}} cdG(h). \tag{18}$$

The government of type ρ intends to minimize $H(\rho, \tilde{h}^*(\hat{\rho}))$ by influencing the public's perception $\hat{\rho}$, given the public's equilibrium response $\tilde{h}^*(\hat{\rho})$ that solves $r\hat{\rho}G(\tilde{h})\tilde{h} - c = 0$.

The social activity threshold $\tilde{h}^{**}(\rho)$ that minimizes the aggregate incremental cost $H(\rho, \tilde{h})$ is unique and lower than $\tilde{h}^*(\rho)$ that would arise in the individuals' equilibrium interaction if the true type ρ is correctly revealed. This is due to the individuals' failure to internalize the externality in their social distancing choice. In addition, $H(\rho, \tilde{h})$ is quasiconvex in $\tilde{h}$ such that the government may prefer to induce a lower equilibrium social activity threshold $\tilde{h}^*$ but not vice versa. This means the government may engage in deceptive communication only if its true type ρ is relatively low, given that $\tilde{h}^*(\cdot)$ is a decreasing function. Nevertheless, too little social activity is not favorable; thus, deceptive communication would not be pursued, even for the type with low ρ, if that would entail a sufficiently high perceived infection rate $\hat{\rho}$. Similar to Lemma 1, I prove that credible communication can arise in equilibrium if and only if (1) $\rho_L < \rho_H$ and $\rho_L \le \rho_{1h}(\rho_H)$ or (2) $\rho_H < \rho_L$ and $\rho_H \le \rho_{1h}(\rho_L)$, where $\rho_{1h}(\cdot)$ is an increasing function. Thus, the results in P_3 can be replicated qualitatively by using $\rho_{1h}(\cdot)$ to replace $\rho_1(\cdot)$ and illustrated in Figure 1.

Moreover, all findings in the "Partially Informative Communication" and "Welfare Implications of Communication Credibility" sections hold qualitatively (the details are omitted to save space). The necessary and sufficient conditions to sustain the semiseparating equilibrium can be identified as in P_4 by using $\rho_{1h}(\cdot)$ and the inverse $\rho_{1h}^{-1}(\cdot)$ and illustrated in Figure 2. This is unsurprising given that the government types' relative incentive to manipulate the public's belief on the incremental infection rate is similar to that in the main model: both $\frac{\partial^2 H(\rho, \tilde{h}^*(\hat{\rho}))}{\partial\hat{\rho}\partial\rho}$ and $\frac{\partial^2 C(\rho, \tilde{c}^*(\hat{\rho}))}{\partial\hat{\rho}\partial\rho}$ are negative. In addition, I can generate the same pattern in Table 1 on the cross-equilibrium comparison of the social welfare, because the manner in which the cross-equilibrium difference in the perceived incremental infection rate affects the aggregate incremental cost (and thus the social welfare) is similar across the settings: both $H(\rho, \tilde{h}^*(\hat{\rho}))$ and $C(\rho, \tilde{c}^*(\hat{\rho}))$ are quasiconvex in $\hat{\rho}$. Therefore, the welfare implications of communication credibility (e.g., on the government's equilibrium expected payoff and on the selection of multiple equilibria) are robust to this alternative setup of heterogenous health cost.

Summary and Discussion

Credibility is essential in social planners' communication about a pandemic (e.g., Simonov et al. 2022; Webster et al. 2020). Governments and health experts may misinform the public about the severity of an infectious disease because their interests on the optimal social distancing may not be aligned; the public's self-isolation tends to be insufficient even from the perspective of a government with an objective to maximize social welfare. Consequently, the government's messages and claims may be distrusted and disregarded, leading to noncompliance with social distancing guidelines.

This research contributes to the literature (e.g., De Véricourt, Gurkan, and Wang 2021) by generating some new results. I show that the impact of the base infection rate on the equilibrium social distancing and the impact of disease contagiousness on the aggregate infection level can be nonmonotonic. I identify equilibrium conditions for truthful communication despite the government's incentive for exaggeration or downplay. Communication can be fully credible as long as the possible levels about the disease's severity are not too close to each other in the public's prior belief. I also show that communication can be partially informative even when full credibility is infeasible and vice versa. An increasing difference between the possible severity levels may enhance or hamper the credibility level of the government's messages. Nevertheless, a higher communication credibility need not always improve social welfare. In addition, communication can be either more or less credible, the more unequal the government balances the isolation and health costs. Moreover, the credibility of communication can be sustained across alternative settings (e.g., communication about the pandemic's base infection rate vs. the contagiousness, individual heterogeneity in the health vs. isolation cost).

My findings can be useful for those who are concerned about the truthfulness of communication during not only the COVID-19 pandemic but also future pandemics. For social planners, such as governments and policy makers, this research can help identify the conditions and the extent to which their plain communication is credible and therefore effective in influencing people's (non)compliance with pandemic control guidelines. They can also learn, from the results on the semiseparating equilibrium, about what messages can be relatively more credible (and when). For example, under the low-type mixing equilibrium, the "low risk" message would be believable but "strong warning" would be questionable. In case the plausibility of cheap talk is limited, social planners may have to resort to other communication channels to manage the public's perception and behavior in fighting the pandemic. For instance, relative to self-quarantine recommendations or press releases, the closure of schools and restaurants would be a costly policy measure that could be used to credibly signal the disease's infectivity. Alternatively, when cheap talk is credible, costly signaling through distortions in the other measures would be unnecessary. Basically, improving the understanding about the effectiveness of costless communication can help social planners gauge the need and the extent to which it should be substituted by distorting other policy measures (e.g., mandatory isolation, vaccination). In addition, they can benefit from my finding that social welfare need not always increase with communication credibility.

Moreover, my research can provide insights to users (e.g., analysts, researchers, investors) of statistics and information related to pandemics. One common measure is the number of recently confirmed cases, which is typically collected and publicized by governments and their agencies. I highlight two potential pitfalls in understanding and using such and other up-to-date indicators of a pandemic's state and severity. The first is the government's incentive to distort the interpretation, aggregation, and timing of confirmed cases to its own advantage. This issue can be particularly relevant for real-time reaction, even when no data fabrication or concealment is involved. My research can help the data users estimate the presence and direction of the potential bias. Such qualitative assessment can also be performed for other government messages and claims, especially when verifiable evidence is absent or limited. Second, the endogeneity in people's social distancing behavior can bias the number of infections as a measure of the disease's inherent characteristics. As I show in P_2, the aggregate infection rate can vary nonmonotonically with the basic reproduction rate. Therefore, the empirically observed case positivity rate need not reflect the disease's true contagiousness. It is critical to correct this bias by controlling the confounding effect of endogenous self-protective behavior. Such bias correction can also be important for the governments that use the number of infections to inform pandemic policies.

My focus on the credibility of communication is motivated mainly by past and future pandemics (e.g., the COVID-19 pandemic). One key feature of my model is that the private provision of social distancing is socially beneficial but insufficient. This basic mechanism and my main insights may apply to other impure public goods with positive externality (e.g., education, environment protection). After all, there are many overlapping features across these settings. Nevertheless, I intend to concentrate on disease infection, and I do not expect to accommodate or capture all important issues in the other contexts. For example, education may yield the private benefit of signaling to potential employers, and environment protection can be provided by the social planner as a pure public good as well. Conversely, the relevance of government communication in other markets may not be immediately clear but deserves further motivation. I hope that my research can tighten the connection between the public good and the cheap talk literature by inspiring more studies on similar and other related research issues.

In practice, people's health states and infection rates may evolve over time. My one-period model can be viewed as a partial approximation of the infection dynamics. This can be seen by noting that p and $E[q^*]$ can represent the infection rate at the beginning and in the current period, respectively. This approach enables me to take the base infection rate p as a model primitive, while focusing on how social distancing may endogenously influence the effective infection probability q in the current period. Basically, my aim is to examine how the equilibrium credibility of communication may vary with exogenous changes in the pandemic's severity (p or r) over time, regions, and/or diseases.

My setup can be enriched by considering the intertemporal trajectory of disease transmission (e.g., Farboodi, Jarosch, and Shimer 2021). The government's communication can still be treated as happening only in the initial period if it is not updated as frequently as the pandemic diffusion. The disease contagiousness r would be relevant for communication, rather than the base infection rate p, which would be time varying and cease to be the government's first-period private information. Another practical issue in a dynamic setting is that deceptive communication may backfire and be punished in the future due to, for example, reputational concerns. This can be captured in a reduced-form way by following the literature on deceptive advertising (Piccolo, Tedeschi, and Ursino 2015; Rhodes and Wilson 2018) to assume that the government would incur a reputation cost $\delta > 0$ should its private information be misreported. One may expect that the parameter space to support credible communication would be expanded. Nevertheless, my main insights would continue to hold even in the presence of dynamic infection and reputation consideration, because the government would still face similar trade-offs in influencing the public's perception and behavior.

Alternatively, the government may update its communication in each period whenever it is privately informed. My insights can be extended to such scenario of repeated interactions, if the parties are myopic enough and do not care too much about future payoffs, which is not unreasonable. However, there are many conceptual and technical difficulties in formulating and solving problems of dynamic cheap talk. For example, it would be unclear how to specify the public's off-equilibrium beliefs if conflicting messages about r are received across periods. This is a unique issue for cheap talk models in which the message space is part of the equilibrium but not the game. Another issue is that the government's private information about p per se would be endogenous and history dependent. In general, it is extremely challenging and easily intractable to construct and analyze dynamic models of costless communication, especially when the information sender takes multiple actions or conveys repeated messages. I hope progress can be made in future research to tackle these issues, probably in simpler nonpandemic contexts.

I assume that the individuals' belief about their health state is unbiased; that is, their perception about their probability of having been initially infected is true and equal to the base infection rate. In practice people may have biased beliefs and may over- or underestimate their infection risks. This possibility can be considered in future research. Nevertheless, the insights I present can still hold, as long as the bias is not extreme and people are still gaining partial information from the base infection rate, which is likely, especially for the COVID-19 pandemic (based on personal and anecdotal observations and experiences).

My microfounded infection model can be extended to study other related problems (e.g., mandatory quarantine). It may be interesting to investigate the role of rapid testing or other antipandemic measures such as vaccination. Depending on the test outcome, people would become ex post heterogeneous in their belief about their original health state ω. Unless the test is perfect and taken by all people, their prior and posterior perceptions about ω can still be manipulated by the government. In addition, testing behavior can be endogenously affected by people's perception about the pandemic's severity (p or r). Thus, the government may have extra motivation to manage the individuals' perception about the pandemic, besides the influence on social distancing. Incorporating these factors (the added heterogeneity and/or action) would enrich and complicate the equilibrium interaction among the individuals, but it is unlikely to invalidate my main insights.

Appendix

Proof of P_1

Taking the derivative of the left-hand side of Equation 4 with respect to $\tilde{c}$, we have $1 + rp(1-p)hf(\tilde{c})$, which is strictly positive for all $\tilde{c}$. In addition, the left-hand side of Equation 4 becomes $-rp(1-p)h$ (respectively, $\bar{c}$) as $\tilde{c} \to 0$ (respectively, $\tilde{c} \to \bar{c}$). This proves that the solution to Equation 4 is indeed unique and interior.

Applying the implicit function theorem to Equation 4, we have

$$\frac{\partial \tilde{c}^*}{\partial r} = \frac{[1 - F(\tilde{c}^*)]p(1-p)h}{1 + rp(1-p)hf(\tilde{c}^*)} > 0.$$

Similarly, we can readily obtain

$$\frac{\partial \tilde{c}^*}{\partial p} = \frac{r[1 - F(\tilde{c}^*)](1-2p)h}{1 + rp(1-p)hf(\tilde{c}^*)},$$

which is positive for $p < 1/2$, equal to 0 for $p = 1/2$, and negative for $p > 1/2$.

Proof of P_2

Taking the derivative of $E[q^*] = p + r[1 - F(\tilde{c}^*)]^2 p(1-p)$ with respect to r, we obtain

$$\begin{aligned}\frac{dE[q]}{dr} &= \left\{[1 = F(\tilde{c}^*)]^2 - 2r[1 - F(\tilde{c}^*)]f(\tilde{c}^*)\frac{\partial \tilde{c}^*}{\partial r}\right\}p(1-p)\\ &= \left\{1 - \frac{2rf(\tilde{c}^*)p(1-p)h}{1 + rf(\tilde{c}^*)p(1-p)h}\right\}[1 - F(\tilde{c}^*)]^2 p(1-p)\\ &= \frac{1 - rf(\tilde{c}^*)p(1-p)h}{1 + rf(\tilde{c}^*)p(1-p)h}[1 - F(\tilde{c}^*)]^2 p(1-p).\end{aligned}$$

This implies that $\frac{dE[q^*]}{dr}$ has the same sign as $1 - rf(\tilde{c}^*)p(1-p)h$. Substituting Equation 4, we have $1 - rf(\tilde{c}^*)p(1-p)h = 1 - \frac{\tilde{c}^* f(\tilde{c}^*)}{1 - F(\tilde{c}^*)}$, which is decreasing in r if and only if $\frac{cf(c)}{1-F(c)}$ is increasing in c (see Assumption 1) because $\frac{\partial \tilde{c}^*}{\partial r} > 0$. Note that $\tilde{c}^* \to 0$ as $r \to 0$. Let $\tilde{c}_1^*$ be the equilibrium social distancing threshold when $r = 1$. The proposition then follows.

Proof of Lemma 1

Note that although $p_L < p_H$, we can have either $\rho_L < \rho_H$ or $\rho_H < \rho_L$. These two cases are analogous to each other. Therefore, the proof focuses on the case $\rho_L < \rho_H$.

Similar to the proof for P_1, the implicit function theorem can be applied to Equation 10 to obtain the following:

$$\frac{\partial \tilde{c}^*(\hat{\rho})}{\partial \hat{\rho}} = \frac{r[1 - F(\tilde{c}^*(\hat{\rho}))]h}{1 + r\hat{\rho}hf(\tilde{c}^*(\hat{\rho}))} > 0,$$

which implies that $\tilde{c}^*(\hat{\rho})$ is increasing in $\hat{\rho}$.

Taking the partial derivative of $C(\rho, \tilde{c})$ with respect to $\tilde{c}$, we have

$$\frac{\partial C(\rho, \tilde{c})}{\partial \tilde{c}} = \{\tilde{c} - 2r[1 - F(\tilde{c})]\rho h\}f(\tilde{c}).$$

It is evident that $\tilde{c} - 2r[1 - F(\tilde{c})]\rho h$ is increasing in $\tilde{c}$, is negative as $\tilde{c} \to 0$, and converges to $\bar{c}$ as $\tilde{c} \to \bar{c}$. This proves that $C(\rho, \tilde{c})$ is quasiconvex in $\tilde{c}$ and minimized at the interior point $\tilde{c}^{**}(\rho) = \text{argmin}_E C(\rho, \tilde{c})$, which is the implicit solution to $\tilde{c} - 2r[1 - F(\tilde{c})]\rho h = 0$. In comparison with Equation 10, it can be readily seen that $\tilde{c}^*(\rho) < \tilde{c}^{**}(\rho)$ for all ρ. In addition, by the quasiconvexity of $C(\rho, \tilde{c})$, $\frac{\partial C(\rho, \tilde{c})}{\partial \tilde{c}}$ is less than 0 for all $\tilde{c}$ that is not higher than $\tilde{c}^*(\rho)$. This implies that $C(\rho_H, \tilde{c}^*(\rho_H)) < C(\rho_H, \tilde{c}^*(\rho_L))$ for all $\rho_L < \rho_H$ because $\tilde{c}^*(\rho_L) < \tilde{c}^*(\rho_H)$. In other words, the IC_H^C constraint is always satisfied for all $\rho_L < \rho_H$.

Consider the IC_L^C constraint. Taking the total derivative of $C(\rho_L, \tilde{c}^*(\rho_L))$ with respect to ρ_L leads to

$$\begin{aligned}\frac{dC(\rho_L, \tilde{c}^*(\rho_L))}{d\rho_L} &= \{\tilde{c}^*(\rho_L) - 2r[1 - F(\tilde{c}^*(\rho_L))]\rho_L h\} f(\tilde{c}^*(\rho_L)) \\ &\quad \times \frac{\partial \tilde{c}^*(\rho_L)}{\partial \rho_L} + r[1 - F(\tilde{c}^*(\rho_L))]^2 h \\ &= \{\tilde{c}^*(\rho_L) - 2r[1 - F(\tilde{c}^*(\rho_L))]\rho_L h\} f(\tilde{c}^*(\rho_L)) \\ &\quad \times \frac{r[1 - F(\tilde{c}^*(\rho_L))]h}{1 + r\rho_L h f(\tilde{c}^*(\rho_L))} + r[1 - F(\tilde{c}^*(\rho_L))]^2 h \\ &= r[1 - F(\tilde{c}^*(\rho_L))]^2 h \frac{1}{1 + r\rho_L h f(\tilde{c}^*(\rho_L))} \\ &= r[1 - F(\tilde{c}^*(\rho_L))]^2 h \frac{1}{\frac{1 + \tilde{c}^*(\rho_L) f(\tilde{c}^*(\rho_L))}{1 - F(\tilde{c}^*(\rho_L))}},\end{aligned}$$

where the last two steps are obtained by substituting $\tilde{c}^*(\rho_L) - r[1 - F(\tilde{c}^*(\rho_L))]\rho_L h = 0$ (see Equation 10). Therefore, $\frac{dC(\rho_L, \tilde{c}^*(\rho_L))}{d\rho_L}$ is positive and decreasing in ρ_L, given Assumption 1, and $\tilde{c}^*(\rho_L)$ is increasing in ρ_L; that is, $C(\rho_L, \tilde{c}^*(\rho_L))$ is increasing and concave in ρ_L.

In addition, taking the total derivative of $C(\rho_L, \tilde{c}^*(\rho_H))$ with respect to ρ_L yields

$$\frac{dC(\rho_L, \tilde{c}^*(\rho_H))}{d\rho_L} = r[1 - F(\tilde{c}^*(\rho_H))]^2 h,$$

which is independent of ρ_L.

It can be readily checked that $\frac{dC(\rho_L, \tilde{c}^*(\rho_L))}{d\rho_L} < \frac{dC(\rho_L, \tilde{c}^*(\rho_H))}{d\rho_L}$ as $\rho_L \to \rho_H$. In addition, $C(\rho_L, \tilde{c}^*(\rho_L)) - C(\rho_L, \tilde{c}^*(\rho_H)) < 0$ as $\rho_L \to 0$ because $\tilde{c}^*(\rho_L)$ would converge to 0, and $C(\rho_L, \tilde{c}^*(\rho_L)) - C(\rho_L, \tilde{c}^*(\rho_H)) \to 0$ as $\rho_L \to \rho_H$. Therefore, because $C(\rho_L, \tilde{c}^*(\rho_L)) - C(\rho_L, \tilde{c}^*(\rho_H))$ is concave in ρ_L, there must exist a unique and interior $\rho_1(\rho_H)$ that is between 0 and ρ_H, for any ρ_H, such that $C(\rho_L, \tilde{c}^*(\rho_L)) \le C(\rho_L, \tilde{c}^*(\rho_H))$ if and only if $\rho_L \le \rho_1(\rho_H)$.

The implicit function $\rho_1(\rho_H)$ is the unique solution of ρ_L to $C(\rho_L, \tilde{c}^*(\rho_L)) - C(\rho_L, \tilde{c}^*(\rho_H)) = 0$. Note that $\frac{dC(\rho_L, \tilde{c}^*(\rho_L))}{d\rho_L} > \frac{dC(\rho_L, \tilde{c}^*(\rho_H))}{d\rho_L}$ at the point $\rho_L = \rho_1(\rho_E)$: $C(\rho_L, \tilde{c}^*(\rho_L))$ crosses $C(\rho_L, \tilde{c}^*(\rho_H))$ once and from below at this point. In addition, the partial derivative of $C(\rho_L, \tilde{c}^*(\rho_H))$, with respect to ρ_H, is positive for any $\rho_H > \rho_L$ that solves $C(\rho_L, \tilde{c}^*(\rho_L)) - C(\rho_L, \tilde{c}^*(\rho_H)) = 0$ because $C(\rho_L, \tilde{c})$ is quasiconvex in $\tilde{c}$, $C(\rho_L, \tilde{c})$ is decreasing in $\tilde{c}$ at $\tilde{c} = \tilde{c}^*(\rho_L)$, and $\tilde{c}^*(\rho_H)$ is increasing in ρ_H. Therefore, given that $C(\rho_L, \tilde{c}^*(\rho_L))$ is independent of ρ_H, we can apply the implicit function theorem to $C(\rho_L, \tilde{c}^*(\rho_L)) - C(\rho_L, \tilde{c}^*(\rho_H)) = 0$ to obtain that $\rho_1(\rho_H)$ is increasing in ρ_H.

Proof of P_4

I focus on the case $\rho_L < \rho_H$ and therefore $p_H < 1 - p_L$ (the case $\rho_H < \rho_L$ and therefore $p_L > 1 - p_H$ is analogous). I first show that a semiseparating equilibrium in which the ρ_L type reports m_L truthfully and the ρ_H type randomizes between m_H and m_L does not exist. Suppose otherwise. The public's equilibrium belief must be $\hat{p}(m_H) = p_1 = p_H$ and $\hat{p}(m_L) = p_\theta$, where $\theta \in (0, \theta_0)$. Note that although $p_H > p_\theta$, we can have either $\rho_H > \rho_\theta$ or $\rho_H < \rho_\theta$.
If $\rho_H > \rho_\theta$, as I have shown for the unbinding IC_H^C constraint in the separating equilibrium, then $C(\rho_H, \tilde{c}^*(\rho_H)) < C(\rho_H, \tilde{c}^*(\rho_\theta))$. This implies that the ρ_H type would not be indifferent between inducing ρ_H and ρ_θ, a contradiction. If instead $\rho_H < \rho_\theta$, it follows from $C(\rho_H, \tilde{c}^*(\rho_H)) = C(\rho_H, \tilde{c}^*(\rho_\theta))$ that $C(\rho_L, \tilde{c}^*(\rho_H)) - C(\rho_L, \tilde{c}^*(\rho_\theta)) = C(\rho_H, \tilde{c}^*(\rho_H)) - C(\rho_H, \tilde{c}^*(\rho_\theta)) + r[1 - F(\tilde{c}^*(\rho_H))]^2 h(\rho_L - \rho_H) - r[1 - F(\tilde{c}^*(\rho_\theta))]^2 h(\rho_L - \rho_H) < 0$. This implies that the ρ_L type would deviate to send the message m_H to induce p_H.

Consider the semiseparating equilibrium in which the ρ_H type reports m_H truthfully and the ρ_L type randomizes between m_H and m_L. The public's equilibrium belief would be $\hat{p}(m_L) = p_0 = p_L$ and $\hat{p}(m_H) = p_\theta$, where $\theta \in (\theta_0, 1)$. This equilibrium would exist if and only if there is such a ρ_θ that ensures $C(\rho_L, \tilde{c}^*(\rho_L)) = C(\rho_L, \tilde{c}^*(\rho_\theta))$ and $C(\rho_H, \tilde{c}^*(\rho_L)) > C(\rho_H, \tilde{c}^*(\rho_\theta))$. Note that $\rho_L < \rho_H$ (and $p_L < p_H$) implies $\rho_L < \rho_\theta$, whereas ρ_H can be either higher or lower than ρ_θ. As a result, it follows from $C(\rho_H, \tilde{c}^*(\rho_L)) - C(\rho_H, \tilde{c}^*(\rho_\theta)) = C(\rho_L, \tilde{c}^*(\rho_L)) - C(\rho_L, \tilde{c}^*(\rho_\theta)) + r[1 - F(\tilde{c}^*(\rho_L))]^2 h(\rho_H - \rho_L) - E[1 - F(\tilde{c}^*(\rho_\theta))]^2 h(\rho_H - \rho_L)$ that $C(\rho_L, \tilde{c}^*(\rho_L)) = C(\rho_L, \tilde{c}^*(\rho_\theta))$ implies $C(\rho_H, \tilde{c}^*(\rho_L)) > C(\rho_H, \tilde{c}^*(\rho_\theta))$.

If $p_L > \frac{1-\sqrt{1-4\rho_1(1/4)}}{2}$, we would have $C(\rho_L, \tilde{c}^*(\rho_L)) > C(\rho_L, \tilde{c}^*(\rho_\theta))$ for any $\theta \in (0, 1)$, so a necessary condition for the semiseparating equilibrium is $p_L < \frac{1-\sqrt{1-4\rho_1(1/4)}}{2}$. In addition, if $p_H < \frac{1-\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2}$, where $\rho_1^{-1}(\cdot)$ is the inverse function of $\rho_1(\cdot)$, we would have $\rho_L < \rho_\theta < \rho_H$ such that $C(\rho_L, \tilde{c}^*(\rho_L)) > C(\rho_L, \tilde{c}^*(\rho_\theta))$ for any $\theta \in (0, 1)$. In the remaining parameter space, there are two possible scenarios for the existence of some $\theta \in (\theta_0, 1)$ such that $C(\rho_L, \tilde{c}^*(\rho_L)) = C(\rho_L, \tilde{c}^*(\rho_\theta))$.

Scenario 1 is $\frac{1-\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2} < p_H < \frac{1+\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2}$, which is equivalent to $p_L < \frac{1-\sqrt{1-4\rho_1(p_H(1-E))}}{2}$ that implies $C(\rho_L, \tilde{c}^*(\rho_L)) < C(\rho_L, \tilde{c}^*(\rho_H))$. There would exist a semiseparating equilibrium where the belief $\theta^* \in (\theta_0, 1)$ is determined by $C(\rho_L, \tilde{c}^*(\rho_L)) = C(\rho_L, \tilde{c}^*(\rho_\theta))$ if and only if $C(\rho_L, \tilde{c}^*(\rho_L)) > C(\rho_L, \tilde{c}^*(\rho_{\theta_0}))$ (i.e., $p_H < \frac{1-2(1-\theta_0)p_L-\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2\theta_0}$). The equilibrium mixing probability that generates θ^* is then $\beta^* = \frac{\theta_0(1-\theta^*)}{(1-\theta_0)\theta^*}$. It is evident that as p_H approaches $\frac{1-\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2}$ or $\frac{1+\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2}$, we would have

$\theta^* \to 1$, which implies $\beta^* \to 0$. Moreover, as p_H approaches $\frac{1-2(1-\theta_0)p_L-\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2\theta_0}$, we would have $\theta^* \to \theta_0$, which implies $\beta^* \to 1$.

Scenario 1′ is $p_H > \frac{1+\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2}$, which implies $p_L > \frac{1-\sqrt{1-4\rho_1(p_H(1-p_H))}}{2}$ and therefore $C(\rho_L, \tilde{c}^*(\rho_L)) > C(\rho_L, \tilde{c}^*(\rho_H))$. The semiseparating equilibrium would exist where the belief $\theta^* \in (\theta_0, 1)$ solves $C(\rho_L, \tilde{c}^*(\rho_L)) = C(\rho_L, \tilde{c}^*(\rho_\theta))$ if and only if $p_H < \frac{1-2(1-\theta_0)p_L+\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2\theta_0}$. The equilibrium mixing probability is still given by $\beta^* = \frac{\theta_0(1-\theta^*)}{(1-\theta_0)\theta^*}$. It is evident that as p_H approaches $\frac{1+\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2}$, we would have $\theta^* \to 1$, which implies $\beta^* \to 0$. Moreover, as p_H approaches $\frac{1-2(1-\theta_0)p_L+\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2\theta_0}$, we would have $\theta^* \to \theta_0$, which implies $\beta^* \to 1$.

Note that for sufficiently low p_L, we have $\frac{1-\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2} < \frac{1-2(1-\theta_0)p_L-\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2\theta_0}$ and $\frac{1+\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2} < \frac{1-2(1-\theta_0)p_L+\sqrt{1-4\rho_1^{-1}(p_L(1-p_L))}}{2\theta_0}$. This implies that the parameter space for the existence of the semiseparating equilibrium is nonempty in either Scenario 1 or 1′.

Impact of Communication Credibility on Equilibrium Social Welfare

To show how to derive the results in Table 1 on the comparison of the social welfare across the different equilibria, I focus on the case $\rho_L < \rho_H$. The alternative case $\rho_H < \rho_L$ can be similarly derived. I rely on comparing the aggregate incremental cost $C(\rho, \tilde{c}^*(\hat{\rho}))$ across the equilibria, which is negatively related to the respective social welfare. Note that the comparison hinges on the equilibrium difference in the perceived incremental infection rate $\hat{\rho}$.

Consider the parameter region A_1 where all three kinds of equilibrium coexist. The perceived incremental infection rate $\hat{\rho}$ for the low type under the pooling, the low-type mixing, and the separating equilibrium is ρ_{θ_0}, ρ_L (or ρ_θ), and ρ_L, respectively. It follows immediately that $SW_L^1 = SW_L^2$ because the low type is indifferent between inducing ρ_L and ρ_θ under the semiseparating equilibrium and would induce ρ_L in the separating equilibrium. As in the proof for P_4, we have $\rho_L < \rho_{\theta_0} < \rho_\theta$. It then follows that $C(\rho_L, \tilde{c}^*(\rho_{\theta_0})) < C(\rho_L, \tilde{c}^*(\rho_L))$ because $C(\rho, \tilde{c})$ is quasiconvex in $\tilde{c}$, $\tilde{c}^*(\rho)$ is an increasing function, and $C(\rho_L, \tilde{c}^*(\rho_L)) = C(\rho_L, \tilde{c}^*(\rho_\theta))$. Therefore, we have $SW_L^0 > SW_L^1$. In addition, note that $\tilde{c}^*(\rho_{\theta_0})$ can be equal to $\tilde{c}^{**}(\rho_L)$, implying that SW_L^0 can achieve the social optimum for the low type. By contrast, the perceived incremental infection rate for the high type under the pooling, the low-type mixing, and the separating equilibrium is ρ_{θ_0}, ρ_θ, and ρ_H, respectively. It follows from $\rho_{\theta_0} < \rho_\theta < \rho_H$ and $\tilde{c}^*(\rho_H) < \tilde{c}^{**}(\rho_H)$ that $C(\rho_H, \tilde{c}^*(\rho_{\theta_0})) > C(\rho_H, \tilde{c}^*(\rho_\theta)) > C(\rho_H, \tilde{c}^*(\rho_H))$, which implies $SW_H^0 < SW_H^1 < SW_H^2$.

In the parameter region $A \backslash A_1$, the perceived incremental infection rate $\hat{\rho}$ for the low type under the pooling and the separating equilibrium is ρ_{θ_0} and ρ_L, and the perceived incremental infection rate $\hat{\rho}$ for the high type is ρ_{θ_0} and ρ_H, respectively. For the low type, we have $\rho_{\theta_0} > \rho_\theta$, where ρ_θ is such that $C(\rho_L, \tilde{c}^*(\rho_L)) = C(\rho_L, \tilde{c}^*(\rho_\theta))$. This implies $C(\rho_L, \tilde{c}^*(\rho_{\theta_0})) > C(\rho_L, \tilde{c}^*(\rho_L))$ and therefore $SW_L^0 < SW_L^1$. Nevertheless, ρ_{θ_0} can be either lower or higher than ρ_H. We would have $C(\rho_H, \tilde{c}^*(\rho_{\theta_0})) > C(\rho_H, \tilde{c}^*(\rho_H))$ and therefore $SW_H^0 < SW_H^2$ when ρ_{θ_0} is lower or sufficiently higher than ρ_H. Alternatively, when ρ_{θ_0} is not much higher than ρ_H, $C(\rho_H, \tilde{c}^*(\rho_{\theta_0}))$ would be lower than $C(\rho_H, \tilde{c}^*(\rho_H))$, and SW_H^0 can reach the social optimum for the high type and would be higher than SW_H^2.

In the parameter region A_2, the perceived incremental infection rate $\hat{\rho}$ for the low type under the pooling and the low-type mixing equilibrium is ρ_{θ_0} and ρ_L (or ρ_θ), respectively, where $\rho_{\theta_0} > \rho_L$. Depending on whether ρ_{θ_0} is lower or higher than ρ_θ, we would have $C(\rho_L, \tilde{c}^*(\rho_{\theta_0})) < C(\rho_L, \tilde{c}^*(\rho_L))$ or $C(\rho_L, \tilde{c}^*(\rho_{\theta_0})) > C(\rho_L, \tilde{c}^*(\rho_L))$ and therefore $SW_L^0 > SW_L^1$ or $SW_L^0 < SW_L^1$, respectively. In case ρ_{θ_0} is lower than ρ_θ, it is possible for SW_L^0 to reach the low type's social optimum. By contrast, the perceived incremental infection rate $\hat{\rho}$ for the high type under the pooling and the low-type mixing equilibrium is ρ_{θ_0} and ρ_θ, respectively, where $\rho_\theta > \rho_H$. Given that the order between ρ_{θ_0} and ρ_θ is indeterminate, so is the order between $C(\rho_H, \tilde{c}^*(\rho_{\theta_0}))$ and $C(\rho_H, \tilde{c}^*(\rho_\theta))$ or SW_H^0 and SW_H^1. We can have $C(\rho_H, \tilde{c}^*(\rho_{\theta_0})) > C(\rho_H, \tilde{c}^*(\rho_\theta))$ and $SW_H^0 < SW_H^1$, if ρ_{θ_0} is sufficiently higher than ρ_θ. Moreover, either SW_H^0 or SW_H^1 can reach the high type's social optimum.

Proof of Lemma 2

I separate the proof into two main parts, which involve different parameter range and results. In each part I focus on the case $\rho_L < \rho_H$; the other case $\rho_H < \rho_L$ is analogous.

Lemma 2, part 1

First, consider the case $\alpha < 2$. The results and the proof are similar to those in the main model (see Lemma 1). Taking the partial derivative of $C_\alpha(\rho, \tilde{c})$ with respect to $\tilde{c}$, we have

$$\frac{\partial C_\alpha(\rho, \tilde{c})}{\partial \tilde{c}} = \{\alpha\tilde{c} - 2r[1 - F(\tilde{c})]\rho h\} f(\tilde{c}).$$

We can then readily obtain that $C_\alpha(\rho, \tilde{c})$ is quasiconvex in $\tilde{c}$ and minimized at the interior point $\tilde{c}_\alpha^{**}(\rho) = \text{argmin}_{\tilde{c}} C_a(\rho, \tilde{c})$, which is the implicit solution to $\alpha\tilde{c} - 2r[1 - F(\tilde{c})]\rho h = 0$. In addition, $\tilde{c}^*(\rho) < \tilde{c}_\alpha^{**}(\rho)$ for all ρ. By the quasiconvexity of $C_\alpha(\rho, \tilde{c})$, we have $C_\alpha(\rho_H, \tilde{c}^*(\rho_H)) < C_\alpha(\rho_H, \tilde{c}^*(\rho_L))$ for all $\rho_L < \rho_H$, because $\tilde{c}^*(\rho_L) < \tilde{c}^*(\rho_H)$. Therefore, the IC constraint for the high type is always satisfied for all $\rho_L < \rho_H$.

Consider the IC constraint for the low type ρ_L. Taking the total derivative of $C_\alpha(\rho_L, \tilde{c}^*(\rho_L))$ with respect to ρ_L leads to

$$\begin{aligned}\frac{dC_\alpha(\rho_L, \tilde{c}^*(\rho_L))}{d\rho_L} &= \{\alpha\tilde{c}^*(\rho_L) - 2r[1 - F(\tilde{c}^*(\rho_L))]\rho_L h\} f(\tilde{c}^*(\rho_L)) \\ &\quad \times \frac{\partial \tilde{c}^*(\rho_L)}{\partial \rho_L} + r[1 - F(\tilde{c}^*(\rho_L))]^2 h \\ &= \{\alpha\tilde{c}^*(\rho_L) - 2r[1 - F(\tilde{c}^*(\rho_L))]\rho_L h\} f(\tilde{c}^*(\rho_L)) \\ &\quad \times \frac{r[1 - F(\tilde{c}^*(\rho_L))]h}{1 + r\rho_L h f(\tilde{c}^*(\rho_L))} + r[1 - F(\tilde{c}^*(\rho_L))]^2 h \\ &= r[1 - F(\tilde{c}^*(\rho_L))]^2 \\ &\quad \times h\left[1 + (\alpha - 2)\frac{r\rho_L h f(\tilde{c}^*(\rho_L))}{1 + r\rho_L h f(\tilde{c}^*(\rho_L))}\right] \\ &= r[1 - F(\tilde{c}^*(\rho_L))]^2 \\ &\quad \times h\left[1 + (\alpha - 2)\frac{\frac{\tilde{c}^*(\rho_L) f(\tilde{c}^*(\rho_L))}{1 - F(\tilde{c}^*(\rho_L))}}{1 + \frac{\tilde{c}^*(\rho_L) f(\tilde{c}^*(\rho_L))}{1 - F(\tilde{c}^*(\rho_L))}}\right],\end{aligned}$$

where the last two steps are obtained by substituting $\tilde{c}^*(\rho_L) - r[1 - F(\tilde{c}^*(\rho_L))]\rho_L h = 0$ (see Equation 10). Thus, $\frac{dC_\alpha(\rho_L, \tilde{c}^*(\rho_L))}{d\rho_L}$ is decreasing in ρ_L, given Assumption 1 and $\tilde{c}^*(\rho_L)$ is increasing in ρ_L; that is, $C_\alpha(\rho_L, \tilde{c}^*(\rho_L))$ is concave, but need not always be increasing, in ρ_L.

In addition, note that $C_\alpha(\rho_L, \tilde{c}^*(\rho_H))$ is linear in ρ_L, $C_\alpha(\rho_L, \tilde{c}^*(\rho_L)) - C_\alpha(\rho_L, \tilde{c}^*(\rho_H)) < 0$ as $\rho_L \to 0$, and $\frac{dC_\alpha(\rho_L, \tilde{c}^*_\alpha(\rho_L))}{d\rho_L} < \frac{dC_\alpha(\rho_L, \tilde{c}^*(\rho_H))}{d\rho_L}$ and $C_\alpha(\rho_L, \tilde{c}^*(\rho_L)) - C_\alpha(\rho_L, \tilde{c}^*(\rho_H)) \to 0$ as $\rho_L \to \rho_H$. Therefore, because $C_\alpha(\rho_L, \tilde{c}^*(\rho_L)) - C_\alpha(\rho_L, \tilde{c}^*(\rho_H))$ is concave in ρ_L, there must exist a unique and interior $\rho_\alpha(\rho_H)$ that is between 0 and ρ_H, for any ρ_H, such that $C_\alpha(\rho_L, \tilde{c}^*(\rho_L)) \leq C_\alpha(\rho_L, \tilde{c}^*(\rho_H))$ if and only if $\rho_L \leq \rho_\alpha(\rho_H)$.

The implicit function $\rho_\alpha(\rho_H)$ can be obtained by solving $C_\alpha(\rho_L, \tilde{c}^*(\rho_L)) - C_\alpha(\rho_L, \tilde{c}^*(\rho_H)) = 0$. Note that at the point $\rho_L = \rho_\alpha(\rho_H)$ we have $\frac{dC_\alpha(\rho_E, \tilde{c}^*(\rho_L))}{d\rho_L} > \frac{dC_\alpha(\rho_L, \tilde{c}^*(\rho_H))}{d\rho_L}$, the partial derivative of $C_\alpha(\rho_L, \tilde{c}^*(\rho_H))$ with respect to ρ_H is positive, and $C_\alpha(\rho_L, \tilde{c}^*(\rho_L))$ is independent of ρ_H. Moreover, we have $\frac{\partial C_\alpha(\rho_L, \tilde{c}^*(\rho_L))}{\partial\alpha} = \int_0^{\tilde{c}^*(\rho_L)} c dF(c) < \frac{\partial C_\alpha(\rho_L, \tilde{c}^*(\rho_H))}{\partial\alpha} = \int_0^{\tilde{c}^*(\rho_H)} c dF(c)$ because $\tilde{c}^*(\rho_L) < \tilde{c}^*(\rho_H)$. We can then apply the implicit function theorem to $C_\alpha(\rho_L, \tilde{c}^*(\rho_L)) - C_\alpha(\rho_L, \tilde{c}^*(\rho_H)) = 0$ to obtain that the function $\rho_\alpha(\rho_H)$ is increasing in ρ_H and α.

Lemma 2, part 2

Then, consider the case $\alpha > 2$. Similarly, it is evident that $C_\alpha(\rho, \tilde{c})$ is still quasiconvex in $\tilde{c}$, and the interior solution $\tilde{c}^{**}_\alpha(\rho) = \text{argmin}_{\tilde{c}} C_\alpha(\rho, \tilde{c})$ can be obtained from the implicit function $\alpha\tilde{c} - 2r[1 - F(\tilde{c})]\rho h = 0$. However, we now have $\tilde{c}^*(\rho) > \tilde{c}^{**}_\alpha(\rho)$ for all ρ and $C_\alpha(\rho_L, \tilde{c}^*(\rho_L)) < C_\alpha(\rho_L, \tilde{c}^*(\rho_H))$ for all $\rho_L < \rho_H$ because $\tilde{c}^*(\rho_L) < \tilde{c}^*(\rho_H)$. This implies that the IC constraint for the low type is always satisfied for all $\rho_L < \rho_H$.

Consider the IC constraint for the high type ρ_H. Given that $C_\alpha(\rho_H, \tilde{c})$ is quasiconvex in $\tilde{c}$ and $\frac{\partial C_\alpha(\rho_H, \tilde{c})}{\partial \tilde{c}} > 0$ at $\tilde{c} = \tilde{c}^*(\rho_H)$, $\frac{\partial C_\alpha(\rho_H, \tilde{c}^*(\rho_L))}{\partial \rho_L}$ is negative for $\tilde{c}^*(\rho_L) < \tilde{c}^{**}(\rho_H)$ and positive for $\tilde{c}^*(\rho_L) > \tilde{c}^{**}(\rho_H)$. Note also that $C_\alpha(\rho_H, \tilde{c}^*(\rho_L)) \to C_\alpha(\rho_H, \tilde{c}^*(\rho_H))$ as $\rho_L \to \rho_H$. Therefore, $C_\alpha(\rho_H, \tilde{c}^*(\rho_H)) \geq C_\alpha(\rho_H, \tilde{c}^*(\rho_L))$ for all $\rho_L < \rho_H$ if and only if $C_\alpha(\rho_H, \tilde{c}^*(\rho_H)) \geq C_\alpha(\rho_E, \tilde{c}^*(0)) = r\rho_H h$. It follows that, because $C_\alpha(\rho_H, \tilde{c}^*(\rho_H))$ is increasing in α, we must have $C_\alpha(\rho_H, \tilde{c}^*(\rho_H)) \geq C_\alpha(\rho_H, \tilde{c}^*(\rho_L))$ for all $\rho_L < \rho_H$, implying that the IC constraint for the high type is violated (i.e., $\rho_\alpha(\rho_H) = 0$) if and only if α is above some cutoff point. In addition, when α is strictly below this cutoff point but still above 2, there would exist a unique and interior $\rho_\alpha(\rho_H)$ that is between 0 and ρ_H, for any ρ_H, such that $C_\alpha(\rho_H, \tilde{c}^*(\rho_H)) \leq C_\alpha(\rho_H, E^*(\rho_L))$ if and only if $\rho_L \leq \rho_\alpha(\rho_H)$.

When the implicit function $\rho_\alpha(\rho_H)$ is interior (i.e., α is not too high), it can be obtained by solving $C_\alpha(\rho_H, \tilde{c}^*(\rho_H)) - C_\alpha(\rho_H, \tilde{c}^*(\rho_L)) = 0$. Note that at the point $\rho_L = \rho_\alpha(\rho_H)$ we have $\frac{\partial C_\alpha(\rho_H, \tilde{c}^*(\rho_H))}{\partial \rho_L} = 0 > \frac{\partial C_\alpha(\rho_H, \tilde{c}^*(\rho_L))}{\partial \rho_L}$. Moreover, $\frac{\partial C_\alpha(\rho_H, \tilde{c}^*(\rho_H))}{\partial\alpha} = \int_0^{\tilde{c}^*(\rho_H)} c dF(c) > \frac{\partial C_\alpha(\rho_H, \tilde{c}^*(\rho_L))}{\partial\alpha} = \int_0^{\tilde{c}^*(\rho_L)} c dF(c)$, because $\tilde{c}^*(\rho_H) > \tilde{c}^*(\rho_L)$. We can then apply the implicit function theorem to $C_\alpha(\rho_H, \tilde{c}^*(\rho_H)) - C_\alpha(\rho_H, \tilde{c}^*(\rho_L)) = 0$ to obtain that the function $\rho_\alpha(\rho_H)$ is decreasing in α.

Note that $\rho_\alpha(\rho_H)$ need not be monotonic in ρ_H because even at the point $\rho_L = \rho_\alpha(\rho_H)$, $\frac{\partial C_\alpha(\rho_H, \tilde{c}^*(\rho_H))}{\partial \rho_H}$ can be either higher or lower than $\frac{\partial C_\alpha(\rho_H, \tilde{c}^*(\rho_L))}{\partial \rho_H} = r[1 - F(\tilde{c}^*(\rho_L))]^2 h$. This is in turn because, given $\alpha > 2$, $\frac{\partial C_\alpha(\rho_H, \tilde{c}^*(\rho_H))}{\partial \rho_H}$ need not be monotonic in ρ_H. Nevertheless, when $F(\cdot)$ is uniform, we have $\rho_\alpha(\rho_H) = \max\left\{\frac{[(4-\alpha)\bar{c} + 2r\rho_H h]\rho_H}{\alpha \mathring{A} + 2(\alpha - 1)r\rho_H h}, 0\right\}$, which is increasing (strictly so when $\rho_\alpha(\rho_H) > 0$) in ρ_H. It can also be readily verified in this example that $\rho_\alpha(\rho_H)$ is decreasing in α and $\rho_\alpha(\rho_H) > 0$ when $\alpha < 4 + 2r\rho_H h/\bar{c}$.

Finally, when $\alpha = 2$, $C_\alpha(\rho, \tilde{c})$ continues to be quasiconvex in $\tilde{c}$, and the interior solution $\tilde{c}^{**}_\alpha(\rho) = \text{argmin}_{\tilde{c}} C_\alpha(\rho, E)$ is equal to $\tilde{c}^*(\rho)$ for all ρ. It follows that the IC constraints are always satisfied for both types, for any $\rho_L \neq \rho_H$. In other words, we have the corner solution $\rho_\alpha(\rho_H) = \rho_H$ and the credible-communication equilibrium can always arise.

Heterogeneous Health Cost

The left-hand side of Equation 16 is strictly increasing in $\tilde{h}$. As $\tilde{h} \to \underline{h}$, the left-hand side of Equation 16 becomes $-c$. In addition, as $\tilde{h} \to \bar{h}$, it becomes $rp(1 - p)\bar{h} - c$, which is positive given the assumption that $\bar{h}$ is sufficiently high. This proves that the solution to Equation 16 is indeed unique and interior. Applying the implicit function theorem to Equation 16, we have

$$\frac{\partial \tilde{h}^*}{\partial r} = -\frac{G(\tilde{h}^*)\tilde{h}^*}{r[G(\tilde{h}^*) + g(\tilde{h}^*)\tilde{h}^*]} < 0.$$

Similarly, we can readily obtain

$$\frac{\partial \tilde{h}^*}{\partial p} = -\frac{(1-2p)G(\tilde{h}^*)\tilde{h}^*}{p(1-p)[G(\tilde{h}^*) + g(\tilde{h}^*)\tilde{h}^*]},$$

which is negative for $p < 1/2$, equal to 0 for $p = 1/2$, and positive for $p > 1/2$.

Taking the derivative of $E[q^*] = p + rp(1-p)G(\tilde{h}^*)^2$ with respect to r, we obtain

$$\begin{aligned}\frac{dE[q^*]}{dr} &= \left[G(\tilde{h}^*)^2 + 2rG(\tilde{h}^*)g(\tilde{h}^*)\frac{\partial \tilde{h}^*}{\partial r}\right]p(1-p)\\ &= \frac{1 - g(\tilde{h}^*)\tilde{h}^*/G(\tilde{h}^*)}{1 + g(\tilde{h}^*)\tilde{h}^*/G(\tilde{h}^*)}G(\tilde{h}^*)^2 p(1-p).\end{aligned}$$

This implies that $\frac{dE[q^*]}{dr}$ has the same sign as $1 - g(\tilde{h}^*)\tilde{h}^*/G(\tilde{h}^*)$, which is decreasing in r if and only if $\frac{hg(h)}{G(h)}$ is decreasing in h (see Assumption 2) because $\frac{\partial \tilde{h}^*}{\partial r} < 0$. To show that $E[q^*]$ can first increase and then decrease with r, consider the Pareto distribution $G(h) = 1 - 1/h$ for $h \geq 1$. The equilibrium social activity threshold is $\tilde{h}^* = 1 + \frac{c}{rp(1-p)}$, and the equilibrium aggregate infection rate is $E[q^*] = p + \frac{rp(1-p)c^2}{[rp(1-p)+c]^2}$. It follows that if $c < p(1-p)$, $E[q^*]$ increases with r for $r \leq \frac{c}{p(1-p)}$ and decreases with r for $r \geq \frac{c}{p(1-p)}$. As another example, when $G(h) = \frac{h-\underline{h}}{\bar{h}-\underline{h}}$, we have $1 - \frac{hg(h)}{G(h)} = -\frac{\underline{h}}{h-\underline{h}}$, which is negative for $\underline{h} > 0$, implying that $E[q^*]$ is decreasing in r.

To characterize the equilibrium conditions to sustain credible communication, I focus on the case $\rho_L < \rho_H$. Taking the partial derivative of $H(\rho, \tilde{h})$ with respect to $\tilde{h}$, we have

$$\frac{\partial H(\rho, \tilde{h})}{\partial \tilde{h}} = \left\{r\rho G(\tilde{h})\tilde{h} + \int_{\underline{h}}^{\tilde{h}} r\rho h dG(h) - c\right\}g(\tilde{h}),$$

where the terms in the curly brackets are increasing in $\tilde{h}$, negative as $\tilde{h} \to \underline{h}$, and positive as $\tilde{h} \to \bar{h}$, given $\bar{h}$ is sufficiently high. This proves that $H(\rho, \tilde{h})$ is quasiconvex in $\tilde{h}$ and minimized at the interior point $\tilde{h}^{**}(\rho) = \text{argmin}_{\tilde{h}} H(\rho, \tilde{h})$. It is evident that $\tilde{h}^*(\rho) > \tilde{h}^{**}(\rho)$ for all ρ. Note also that $\tilde{h}^*(\rho)$ is decreasing in ρ.

By the quasiconvexity of $H(\rho, \tilde{h})$, $\frac{\partial H(\rho, \tilde{h})}{\partial \tilde{h}}$ is positive for all $\tilde{h}$ that is not lower than $\tilde{h}^*(\rho)$. It follows that $H(\rho_H, \tilde{h}^*(\rho_H)) < H(\rho_H, \tilde{h}^*(\rho_L))$ for all $\rho_L < \rho_H$ because $\tilde{h}^*(\rho_L) > \tilde{h}^*(\rho_H)$. This means the IC constraint for the high type is always satisfied for all $\rho_L < \rho_H$.

Consider the IC constraint for the low type. Taking the total derivative of $H(\rho_L, \tilde{h}^*(\rho_L))$ with respect to ρ_L leads to

$$\begin{aligned}\frac{dH(\rho_L, \tilde{h}^*(\rho_L))}{d\rho_L} &= \left\{r\rho_L G(\tilde{h}^*(\rho_L))\tilde{h}^*(\rho_L) + \int_{\underline{h}}^{\tilde{h}^*(\rho_L)} r\rho_L h dG(h) - c\right\}g(\tilde{h}^*(\rho_L))\frac{\partial \tilde{h}^*(\rho_L)}{\partial \rho_L} + \int_{\underline{h}}^{\tilde{h}^*(\rho_L)} rG(\tilde{h}^*(\rho_L))h dG(h)\\ &= \int_{\underline{h}}^{\tilde{h}^*(\rho_L)} r\rho_L h dG(h) g(\tilde{h}^*(\rho_L))\frac{-G(\tilde{h}^*(\rho_L))\tilde{h}^*(\rho_L)}{\rho_L[G(\tilde{h}^*(\rho_L)) + g(\tilde{h}^*(\rho_L))\tilde{h}^*(\rho_L)]} + \int_{\underline{h}}^{\tilde{h}^*(\rho_L)} rG(\tilde{h}^*(\rho_L))h dG(h)\\ &= rG(\tilde{h}^*(\rho_L))\frac{G(\tilde{h}^*(\rho_L))}{G(\tilde{h}^*(\rho_L)) + g(\tilde{h}^*(\rho_L))\tilde{h}^*(\rho_L)}\int_{\underline{h}}^{\tilde{h}^*(\rho_L)} h dG(h)\\ &= rG(\tilde{h}^*(\rho_L))\frac{1}{1 + g(\tilde{h}^*(\rho_L))\tilde{h}^*((\rho_L))/G(\tilde{h}^*(\rho_L))}\int_{\underline{h}}^{\tilde{h}^*(\rho_L)} h dG(h),\end{aligned}$$

where the second step is obtained by substituting $r\rho_L G(\tilde{h}^*(\rho_L))\tilde{h}^*(\rho_L) - c = 0$. Thus, $\frac{dH(\rho_L, \tilde{h}^*(\rho_L))}{d\rho_L}$ is positive and decreasing in ρ_L, given Assumption 2 and $\tilde{h}^*(\rho_L)$ is decreasing in ρ_L; that is, $H(\rho_L, \tilde{h}^*(\rho_L))$ is increasing and concave in ρ_L.

In addition, the total derivative of $H(\rho_L, \tilde{h}^*(\rho_H))$ with respect to ρ_L is independent of ρ_L:

$$\frac{dH(\rho_L, \tilde{h}^*(\rho_H))}{d\rho_L} = \int_{\underline{h}}^{\tilde{h}^*(\rho_H)} rG(\tilde{h}^*(\rho_H))h dG(h).$$

It can be readily checked that $\frac{dH(\rho_L, \tilde{h}^*(\rho_L))}{d\rho_L} < \frac{dH(\rho_L, \tilde{h}^*(\rho_H))}{d\rho_L}$ as $\rho_L \to \rho_H$. In addition, $H(\rho_L, \tilde{h}^*(\rho_L)) - H(\rho_L, \tilde{h}^*(\rho_H)) < 0$ as $\rho_L \to 0$ because $\tilde{h}^*(\rho_L)$ would converge to $\bar{h}$, and $H(\rho_L, \tilde{h}^*(\rho_L)) - H(\rho_L, \tilde{h}^*(\rho_H)) \to 0$ as $\rho_L \to \rho_H$. Therefore, because $H(\rho_L, \tilde{h}^*(\rho_L)) - H(\rho_L, \tilde{h}^*(\rho_H))$ is concave in ρ_L, there must exist a unique and interior $\rho_{1h}(\rho_H)$ that is between 0 and ρ_H, for any ρ_H, such that $H(\rho_L, \tilde{h}^*(\rho_L)) \leq H(\rho_L, \tilde{h}^*(\rho_H))$ if and only if $\rho_L \leq \rho_{1h}(\rho_H)$.

The implicit function $\rho_{1h}(\rho_H)$ is the unique solution of ρ_L to $H(\rho_L, \tilde{h}^*(\rho_L)) - H(\rho_L, \tilde{h}^*(\rho_H)) = 0$. Note that $\frac{dH(\rho_E, \tilde{h}^*(\rho_L))}{d\rho_L} > \frac{dH(\rho_L, \tilde{h}^*(\rho_H))}{d\rho_L}$ at the point $\rho_L = \rho_{1h}(\rho_H)$; $H(\rho_L, \tilde{h}^*(\rho_L))$ crosses $H(\rho_L, \tilde{h}^*(\rho_H))$ once and from below at this point. In addition, the partial derivative of $H(\rho_L, \tilde{h}^*(\rho_H))$ with respect to ρ_H is positive for any $\rho_H > \rho_L$ that solves $H(\rho_L, \tilde{h}^*(\rho_L)) - H(\rho_L, \tilde{h}^*(\rho_H)) = 0$ because $H(\rho_L, \tilde{h})$ is quasiconvex in $\tilde{h}$, $H(\rho_L, \tilde{h})$ is increasing in $\tilde{h}$ at $\tilde{h} = \tilde{h}^*(\rho_L)$, and $\tilde{h}^*(\rho_H)$ is decreasing in ρ_H. Therefore, given that $H(\rho_L, \tilde{h}^*(\rho_L))$ is independent of ρ_H, the implicit function theorem can be applied to

$H(\rho_L, \tilde{h}^*(\rho_L)) - H(\rho_L, \tilde{h}^*(\rho_H)) = 0$ to obtain that $\rho_{1h}(\rho_H)$ is increasing in ρ_H.

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