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Strategic Communications with Socializing Agents under Unknown Public Health Threats

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Abstract. ***Problem definition*****:** This paper investigates how governments can design optimal public health policies to inform and guide the public amid uncertain health threats. To capture heterogeneity in social behavior, we introduce a class of socializing agents and examine how the government strategically combines two policy instruments, persuasive communication (messages) and physical or monetary penalties, to incentivize compliance with social restrictions. ***Methodology/results*****:** We develop a game-theoretic model in which the government commits in advance to both messaging and penalty strategies. The optimal policy exhibits a non-monotonic structure with respect to the pandemic severity, alternating between the use of messages and penalties. Messages are shown to be most effective when the severity of the pandemic is either mild or moderate-to-high. Interestingly, socializing agents can indirectly promote compliance among traditional agents due to negative externalities, and the government may reduce penalty levels as pandemic severity increases. ***Managerial implications*****:** Our findings underscore the strategic value of coordinating messages and penalties as complementary tools in public health policy. When the divergence between individual and governmental incentives is small, costless messages—especially those delivering finely granulated information—can effectively influence public behavior. Notably, we identify a dual role for state-contingent penalties not only in enhancing compliance but also in signaling pandemic severity. Overall, by examining the interplay of multiple policy instruments across different dimensions, our results highlight the importance of behavioral heterogeneity and government credibility in shaping public health policies under competing societal objectives.

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Key words: Pandemic management, Strategic communications, Socializing agents, Signaling with commitments

1. Introduction

In the tug-of-war between COVID-19 and humankind, we are learning and practicing more subtle control measures against the crawling virus. Although the WHO has declared an end to COVID-19 as a global health emergency, the virus continues to evolve. Recent surges driven by emerging variants, such as the NB.1.8.1 ("Nimbus") subvariant, highlight the risk of renewed outbreaks even in highly vaccinated populations (TODAY 2025). At the same time, communicable diseases more broadly continue to emerge, posing persistent threats to public health. For instance, the Centers for Disease Control and Prevention recently issued a health advisory on the resurgence of measles across multiple regions (CDC 2025). Consequently, governments and health organizations must maintain a proactive and sustained role in managing public health crises. Existing research has explored various measures for effective pandemic management and long-term public health regulations (Bavafa et al. 2021, Yang et al. 2022, Liu et al. 2023, Dai and Singh 2025). Among these, limiting close face-to-face contact has proven to be the most effective approach for curbing the spread of communicable diseases such as COVID-19 (Haushofer and Metcalf 2020).

To induce public compliance with social restrictions, government interventions can be broadly categorized into two types: direct (physical) and indirect (informational) measures. Physical measures, such as penalties for rule violations and home quarantine mandates, are widely used to contain the spread of the virus (Chen et al. 2020, Huang et al. 2022, Mak et al. 2022, Acemoglu et al. 2024). However, these stringent policies involve significant resource expenditures, implementation delays, and social or economic costs. Informational interventions provide a more flexible alternative. Governments typically have more timely access to pandemic-related data than the general public, especially as new virus variants emerge unpredictably. By communicating information such as case numbers, death tolls, and fatality rates, they shape public perceptions of epidemic severity and influence individual compliance behaviors (de Véricourt et al. 2021, Simonov et al. 2022, Guo 2024). While prior research has examined the effectiveness of physical and informational interventions separately, the interaction between these two policy tools remains insufficiently understood. Physical measures not only restrict behavior directly but also convey implicit signals about the severity of the pandemic. A common observation is that governments tend to introduce stricter measures as the situation worsens, thereby indirectly communicating its seriousness. This raises important questions about the potential dual function of penalties, serving both as enforcement mechanisms and as informational cues. Furthermore, if physical interventions already communicate severity, are additional informational measures still necessary? To explore this, we examine how governments can strategically combine physical enforcement and informational interventions to improve the effectiveness of pandemic management.

Existing research on pandemic management also explores a key question: what factors contribute to inconsistencies in government policies across regions and countries? Two widely discussed explanations are differences in government priorities and variations in enforcement capacity. First, governments prioritize economic growth and public health differently during a pandemic (Eichenbaum et al. 2021, Birge et al. 2022). While strict social restrictions help control the virus, they also disrupt economic activity. For example, quarantine policies and travel restrictions limit workforce availability across multiple sectors, creating economic trade-offs. Second, enforcement capacity and enforcement costs shape government decisions (Blasimme and Vayena 2020). Physical measures, such as lockdowns and fines, can effectively induce compliance but require significant resources, including enforcement personnel, monitoring systems, and legal frameworks. Our study builds on these perspectives by incorporating both government priorities and enforcement capacity into the analysis of public policy decisions. Beyond these institutional factors, we explore behavioral influences on compliance variations across countries and regions. Specifically, we consider a heterogeneous population consisting of "socializing" and "traditional" agents, where socializing agents have a stronger preference for social interactions. This behavioral distinction helps explain differing responses to government regulations. For example, mask compliance varies across regions despite its widely recognized effectiveness in preventing viral transmission (Badillo-Goicoechea et al. 2021). Similarly, large-scale protests against lockdown measures occurred across Europe, while comparable resistance was less common in East Asia.

Our study investigates how governments can coordinate physical enforcement measures with informational interventions and how different factors shape public policy decisions. Specifically, we address three core questions. (1) How should a government strategically combine pandemic-related information and penalties to incentivize compliance with social restrictions? (2) How do socializing agents, shaped by cultural norms, influence enforcement strategies and decisions regarding information disclosure? (3) How do institutional characteristics, such as government credibility and the relative emphasis on public health versus economic growth, affect policy choices? In the baseline model, we assume that the government pre-commits to a policy that specifies penalties and messages based on the realized severity of the pandemic. Once the uncertainty is resolved, the government enforces the penalty and messaging strategies according to its pre-committed policy. Based on the observed message and penalty, individuals form beliefs about the pandemic severity and choose whether to engage in social activity. A key novelty of our study is the incorporation of heterogeneous preferences for social interactions. We model a society consisting of both socializing and traditional agents, where the former derive additional utility from engaging in social activities.

Our analysis reveals that the government's optimal policy follows a non-monotonic pattern with respect to pandemic severity, driven by a fundamental trade-off between public health protection and enforcement costs. As pandemic severity increases, the social value of compliance grows, prompting the government to adopt more aggressive interventions. However, imposing large penalties incurs substantial enforcement costs, which may lead the government to rely more heavily on costless messaging under certain conditions. Depending on the level of severity, the government is found to alternate between two main intervention strategies:

- **Message-based persuasion (Laissez-faire regime):** When public health risks are low (mild severity), or when voluntary compliance among traditional agents can be sustained (moderate-to-high severity), the government refrains from imposing penalties and instead uses informative messaging to shape public beliefs and induce self-motivated compliance.
- **Penalty-based enforcement (Intermediate-intervention and Zero-out regimes):** When the misalignment between the government's public health objectives and individual incentives becomes more pronounced under moderate or high severity, the government implements state-contingent penalties that fully reveal the level of pandemic severity and directly induce compliance.

The government's choice between these two strategies depends on the degree of misalignment between its public health objectives and individual incentives. Communications are most effective when the misalignment between government and individual incentives is limited. In such cases, the government can rely on costless, finely calibrated messages to guide public behavior effectively. However, when misalignment arises—particularly due to socializing agents imposing negative externalities on traditional agents—the government may find it necessary to adopt penalty-based enforcement. In these situations, penalties serve a dual function: they not only deter noncompliance but also convey information about the severity of the pandemic. Interestingly, we find that the government may commit to and impose lower penalty levels under more severe pandemic conditions. This outcome stems from the dual role of state-contingent penalties. While higher penalties directly promote compliance by increasing the cost of violating public health measures, they also act as signals of severity, thereby encouraging voluntary adherence. This self-reinforcing mechanism allows the government to reduce penalties as severity increases, without compromising compliance. These findings reveal the dual function of penalties and underscore how governments can strategically coordinate messaging and enforcement as complementary tools to design adaptive and situation-specific public health policies.

We further examine how socializing agents and institutional factors influence policy outcomes. While socializing agents generally have a negative impact on pandemic management, they can indirectly promote compliance among traditional agents. This effect highlights the need to carefully combine penalty-based enforcement and message-based persuasion to address population heterogeneity and social externalities. In an extended setting, we consider the government's need to balance dual objectives: public health and economic growth. Although the structure of the optimal policy remains robust, placing greater weight on economic outcomes leads the government to reduce penalties and rely more on message-based persuasion across a wider range of pandemic severity. As the government prioritizes economic activity, its objectives increasingly align with individual incentives, reducing the need for punitive enforcement and enhancing the role of persuasion. We also emphasize the importance of government credibility. When credibility is present, the government can design policies more flexibly and align its objectives with public incentives, leading to better outcomes. In contrast, a lack of credibility imposes binding incentive constraints, limits policy options, and reduces effectiveness. Finally, we generalize our model by introducing a continuous distribution of social interaction preferences and find that our main results remain robust. Together, these findings provide theoretical and practical insights for designing adaptive and context-specific pandemic policies.

The remainder of the paper is structured as follows. Section 2 reviews the related literature. Section 3 introduces the model setup. Section 4 analyzes the benchmark case with complete information and characterizes the public behavior equilibrium. Section 5 presents the optimal public policy and discusses the role of socializing agents. Section 6 explores three extensions: (i) a setting in which the government lacks commitment power, (ii) the incorporation of economic growth into the government's policy objectives, and (iii) a continuous distribution of preferences for social interaction. Finally, Section 7 summarizes the key findings.

2. Literature Review

As societies adapt to the reality of coexisting with pandemics such as COVID-19, increasing attention has been given to pandemic control from economic and management perspectives. Our study contributes to this growing body of literature in two key ways. First, while prior research has largely examined the effects of physical and informational interventions separately in controlling disease spread (Alizamir et al. 2020, Acemoglu et al. 2024, Kang et al. 2023, Bai et al. 2024, Kong et al. 2024), the interaction between these measures remains underexplored. In particular, our work addresses how to characterize the dual function of penalties and determine the optimal combination of policy instruments, including penalties and messaging. By analyzing the interplay between informational and regulatory instruments, we identify the conditions under which the government can rely on either a single tool or a combination of both to enhance pandemic management. In doing so, our study extends the existing literature by evaluating the distinct and complementary roles of policy instruments across multiple dimensions. Second, existing studies have primarily focused on how institutional factors, such as economic growth and public health priorities, shape policy decisions during pandemics (El Ouardighi et al. 2022, Shahmanzari et al. 2023). Our model not only incorporates these factors but also introduces a behavioral perspective by accounting for heterogeneity in individuals' preferences for social interactions. Specifically, we define "socializing agents" as individuals with a strong preference for social engagement, a concept similar to Larson (2007), which distinguishes between agents with high and low levels of social activity based on their frequency of human contact and associated infection risks. In our model, socializing agents derive additional utility from social interactions, as a larger social network enhances their choices and engagement opportunities (Zhou and Chen 2015). By incorporating this behavioral dimension, our study contributes to the literature by examining how variations in social and cultural norms can influence divergent policy responses to emerging pandemics.

Our study also contributes to the literature on strategic communication between policymakers and the public. The way information is conveyed depends on whether the sender has commitment power. Without commitment, communication occurs through signaling or cheap talk (Crawford and Sobel 1982, Stein 1989). In contrast, when the sender has commitment power, they can design an information mechanism before the realization of an uncertain state, a framework known as Bayesian persuasion or information design (Kamenica and Gentzkow 2011, Kamenica 2019). Our work is closely related to de Véricourt et al. (2021) and Guo (2024), both of which examine strategic communication in pandemic management. de Véricourt et al. (2021) analyze a government with commitment power that communicates with the public within the framework of information design, highlighting the trade-off between economic growth and public health when disclosing disease-related information. Guo (2024) studies a social planner without commitment who communicates under a cheap-talk framework, focusing on how policymakers weigh the costs of social distancing against public health concerns. Our study differs from these works and contributes to the literature in two key ways. First, while prior research has primarily focused on the role of informational measures in pandemic management, we examine a government equipped with both informational and regulatory instruments to address public noncompliance. We focus on how these distinct policy tools interact and jointly shape the optimal public policy, thereby highlighting the complementary roles and relative importance of interventions across different dimensions. Second, we analyze government policies under both commitment and non-commitment scenarios. Our baseline model considers a full-credibility government that can commit to a public policy in advance. In contrast, the extension examines a no-credibility government that communicates with the public only after privately observing the pandemic state. Comparing these two settings highlights the value of credibility in enhancing the effectiveness of pandemic management.

3. Basic Model

This section outlines the key components of our model, including the decision processes of the government and the public, the communication process, the information structure, and the sequence of events. First, our model assumes that the severity of the pandemic, denoted by $s \in S$, follows a uniform distribution over $[0, \overline{s}]$, with S being the set of all possible states. The values $s = 0$ and $s = \overline{s}$ represent the mildest and most severe states of the pandemic, respectively.

Information Structure. Before the state s is privately observed, the government commits to a **public policy** $\Gamma = \{\mathbb{F}, P, M\}$, which specifies (i) the set P of all possible penalties p and the set M of all possible messages m and (ii) the mapping function $\mathbb{F} : S \to P \times M$ that jointly determines the penalty and the message issued by the government for each realized state. The public policy Γ is known to the public. Within this information design framework, once the state s is realized, the government enforces the penalty p and communicates the message m according to the pre-committed public policy. Our analysis focuses on pure strategies in the government's policy design. This assumption reflects common policymaking practices, where governments, particularly in health crises, enforce policies in a consistent and transparent manner. In particular, penalties are rarely applied in a randomized fashion, as consistency is crucial for ensuring public compliance and trust. Given the government's policy Γ, the public updates its belief $\mu(s|p, m, \Gamma)$ about the pandemic state based on Bayes' rule:

$$\mu(s|p, m, \Gamma) = \frac{\text{Prob}(m, p|s) * \text{Prob}(s)}{\text{Prob}(m, p)}. \tag{1}$$

Given this posterior belief, we define $\tilde{s}(m,p) \equiv \mathbb{E}[s|p,m,\Gamma]$ as the public's updated expectation of the pandemic state. The posterior belief $\tilde{s}(m,p)$ is computed as follows:

$$\tilde{s}(m,p) = \int_0^{\overline{s}} s\mu(s|p,m,\Gamma)\, ds. \tag{2}$$

For notational convenience, we henceforth denote $\tilde{s}(m,p)$ by $\tilde{s}$, and use the two notations interchangeably when no confusion arises.

The Public. Each agent receives a deterministic utility from social interactions, e.g., working or shopping to meet basic life needs, which is normalized to 1. Meanwhile, all agents face two risks when engaging in social interactions: (i) the risk of being infected and (ii) the risk of the government penalty through a set of restriction policies. Based on available information about the pandemic state and government policies, each agent makes its decision from a binary set $A \in \{0,1\}$, where $A = 1$ indicates that the agent violates social distancing policy and engages in social activities while $A = 0$ indicates that the agent complies with social restrictions. For ease of reference, we use "violation" to represent $A = 1$ and "compliance" for $A = 0$.

A salient feature of this paper is to incorporate behavioral inclinations toward social interactions based on social and cultural norms. Especially, we introduce two kinds of agents (i.e., traditional agents and socializing agents) to capture heterogeneous preferences for social interactions. In particular, compared to traditional agents, socializing agents derive additional utility from engaging in social interactions. This behavioral difference will be formally captured in the utility functions presented below. We normalize the total population size to 1, with a fraction λ representing socializing agents and the remaining $(1-\lambda)$ being traditional agents.

Given the government's policy Γ, after observing the message m and penalty p, traditional agents' utility function is given as follows:

$$u_t = \begin{cases} 1 - p - \tilde{s}\eta, & \text{if } A = 1, \\ 0, & \text{if } A = 0. \end{cases} \tag{3}$$

Note that individuals do not observe the true pandemic state directly; instead, they update their beliefs based on the observed message m and penalty p. The variable η represents the level of social interactions, measured by the proportion of the population engaging in social activities (i.e., the proportion of agents choosing $A = 1$). In equilibrium, the level of social interactions, η^*, is endogenously determined after agents observe the penalty p and form expectations about $\tilde{s}$. The term $\tilde{s}\eta$ reflects the agents' expectation of infection risk, which increases with both perceived pandemic severity and the level of social interactions. In contrast, the utility function of socializing agents is given by:

$$u_s = \begin{cases} 1 - p - \tilde{s}\eta + \beta\eta, & \text{if } A = 1, \\ 0, & \text{if } A = 0. \end{cases} \tag{4}$$

Thus, the two types of agents (traditional and socializing) differ only in their preferences for social interactions, and the socializing agents obtain an additional utility, which is captured by $\beta\eta$. β captures the marginal utility from the social intensity η. We assume that $\beta \geq \bar{s}$, ensuring that socializing agents always receive positive externalities from social interactions under any pandemic state. This assumption sharpens the distinction between agent types and simplifies our analysis regarding behaviors of socializing agents. Further, we generalize the analysis in Section 6.3 by allowing β to vary continuously and demonstrate that our main results remain robust.

Government. The government's primary objective is to protect public health during the pandemic. Given a realized state s, its utility function is defined as:

$$u_g(s) = -s\eta - ap. \tag{5}$$

The first term, $s\eta$, captures the **infection cost**, which characterizes the pandemic threat to public health. The functional form indicates that the infection cost is positively associated with the level of social interactions η and the pandemic severity s. The second term, ap, represents the **enforcement cost**, where a denotes the marginal cost of enforcing penalties. This captures the administrative expenses associated with regulatory measures, such as manpower and material resources required for enforcement. Finally, sending messages is costless for the government, a standard assumption in the information design literature. This assumption aligns with the observation that informational interventions, such as news reporting, are generally more cost-effective than administrative enforcement. In Section 6.2, we extend our basic model by incorporating economic growth into the government's objective. Our main insights remain robust under this extension.

In summary, our baseline model investigates how the government employs two policy instruments (penalties and messages) to safeguard public health during a pandemic. Penalties affect public behavior through two channels: they directly raise the cost of social interactions and implicitly signal the severity of the pandemic. In contrast, messages serve as costless communication tools that convey information about the pandemic state. Our analysis examines how the government optimally combines these distinct instruments under varying conditions.

We illustrate the timeline in Figure 1. In the basic model, the sequence of events proceeds as follows: (1) The government commits to the public policy Γ at the outset, which is disclosed to the public. (2) The government is privately informed about the state s, and chooses p and m according to the pre-committed policy. (3) Upon observing p and m, the public updates the expectation $\tilde{s}(m,p)$ regarding the pandemic severity. Both the traditional agents and the socializing agents simultaneously decide whether to comply or not. For a clear demonstration, key notations in this paper are summarized in Table 1.

Figure 1 **Sequence of Events.**

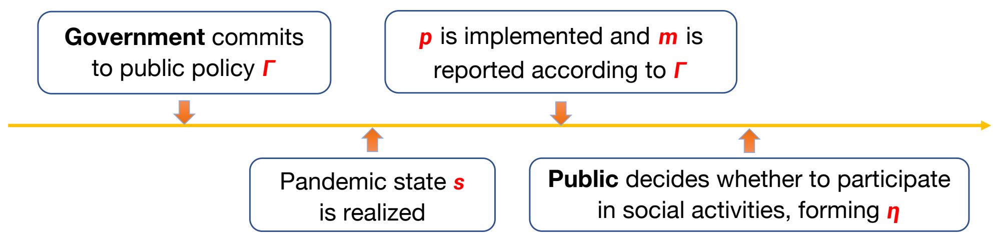


Table 1 **Summary of Key Notations.**

Notation	Description
$s \in S$	Pandemic severity, uniformly distributed over $[0, \bar{s}]$
Γ	Public policy, consisting of set P, set M, and mapping $\mathbb{F}: S \to P \times M$
$p \in P$	Penalty for violating social distancing measures
$m \in M$	Reported message on pandemic severity
$\tilde{s}$	Public's updated expectation about s after observing p and m under Γ
η	Level of social interactions
λ	Proportion of socializing agents
β	Marginal utility of social interactions for socializing agents
a	Marginal cost of enforcing penalty

4. Equilibrium Characterizations of Public Behaviors

We begin with a benchmark scenario in which the public has complete information about the pandemic severity, i.e., $\tilde{s} = s$. In this setting, individuals observe both the penalty p and the actual severity level s, and then decide whether to comply with the social distancing policy. The equilibrium public behavior is jointly determined by the penalty p and the pandemic severity s.

LEMMA 1. *Under the complete information benchmark, the equilibrium level of social interaction $\eta^*(s,p)$ is as follows:*

$$\eta^*(s,p) = \begin{cases} 1, & \text{if } s+p<1, \\ \frac{1-p}{s}, & \text{if } s+p\ge 1 \text{ and } s\lambda+p<1, \\ \lambda, & \text{if } 1\le s\lambda+p<1+\beta\lambda\ , \\ 0, & \text{if } s\lambda+p\ge 1+\beta\lambda. \end{cases} \tag{6}$$

We illustrate the above results using Table 2, which describes how agent behavior evolves with changes in pandemic severity s and penalty p. As pandemic severity s increases and/or the penalty p rises, the equilibrium level of social interactions $\eta^*(s,p)$ evolves through four stages: (i) when $s+p<1$, all agents violate the social distancing policy; (ii) when $s+p\ge 1$ and $s\lambda+p<1$, a fraction of traditional agents comply while all socializing agents still violate; (iii) when $1\le s\lambda+p<1+\beta\lambda$, all traditional agents comply while socializing agents continue to engage in social interactions; and (iv) when $s\lambda+p\ge 1+\beta\lambda$, all agents comply.

Table 2 Equilibrium Behavior of Different Agents.

Penalty p	Pandemic Severity s	Agent Behavior: Traditional	Agent Behavior: Socializing	Social Interaction η^*
$[0,1)$	$[0,1-p)$	Full Violation	Full Violation	1
	$\left[1-p,\frac{1-p}{\lambda}\right)$	**Partial Violation**	Full Violation	$\frac{1-p}{\lambda}$
	$\left[\frac{1-p}{\lambda},\frac{1+\beta\lambda-p}{\lambda}\right)$	No Violation	Full Violation	λ
	$\left[\frac{1+\beta\lambda-p}{\lambda},\bar{s}\right]$	No Violation	No Violation	0
$[1,1+\beta\lambda)$	$\left[0,\frac{1+\beta\lambda-p}{\lambda}\right)$	No Violation	Full Violation	λ
	$\left[\frac{1+\beta\lambda-p}{\lambda},\bar{s}\right]$	No Violation	No Violation	0
$[1+\beta\lambda,+\infty)$	Any	No Violation	No Violation	0

This lemma also implies two key mechanisms through which penalties influence behavior under incomplete information. First, penalties directly increase the cost of violation, thereby raising individuals' incentives to comply. For instance, Table 2 shows that once the penalty reaches a draconian level ($p\ge 1+\beta\lambda$), compliance becomes a dominant strategy for all socializing agents. Second, under incomplete information, penalties also serve as signals of pandemic severity. In addition to their regulatory function, penalties shape public beliefs and influence behavior through informational channels. Given that penalties function both as regulatory instruments and informational signals, the value of information design via direct messages is therefore worth investigating. In the following section, we examine the interaction mechanisms of various policy levers.

5. Optimal Public Policy

This section investigates the government's optimal policy design under incomplete information, where the public cannot directly observe the severity of the pandemic. After characterizing the optimal public policy with two levers, Section 5.1 discusses the value of messages in constructing public policy, and Section 5.2 examines how socializing agents affect policy shaping.

We derive the government's optimal policy and find that it may not be unique. The proof in Proposition 1 provides the full characterization. In the main text, we present the essential structure that arises. Specifically, when penalties partially convey information about the pandemic, the government sends additional messages only if doing so strictly improves its expected utility. Under this characterization, the public policy within a given region of s takes one of two forms: (1) **Separating penalty without messaging:** The government implements state-contingent penalties that vary with the pandemic state. Because these penalties fully reveal the pandemic state, no additional message is needed. For notational convenience, we let $m = m_0$ denote the absence of a message. (2) **Pooling penalty with informative messaging:** The government applies a uniform penalty across all states within a region of s and may use differentiated messages to convey information about pandemic severity. The following proposition characterizes the structure of the government's optimal policy.

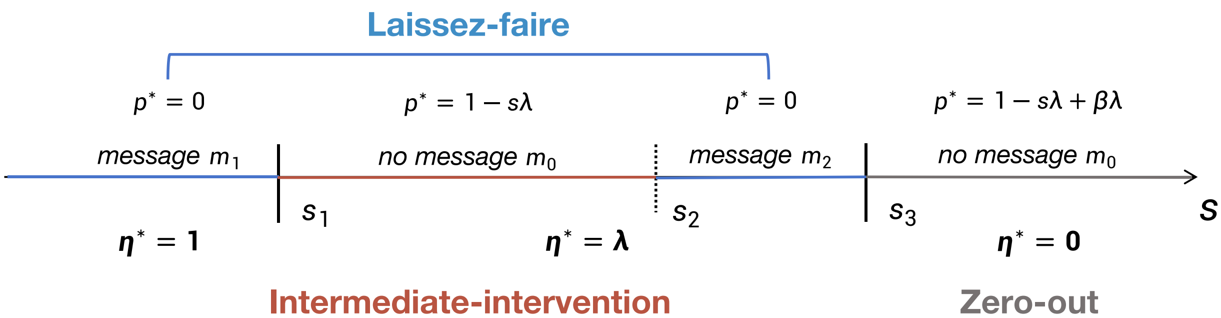
PROPOSITION 1. *There exist three unique thresholds $s_1 < s_2 < s_3$ that partition the state space and determine the government's optimal policy across three distinct regimes:*

- ***Laissez-faire** ($s \le s_1$ and $s_2 < s \le s_3$): The government imposes no penalty ($p^* = 0$) and reports differentiated messages m_1 and m_2 to induce different compliance levels: full violation ($\eta^* = 1$) for $s \le s_1$, and compliance among traditional agents ($\eta^* = \lambda$) for $s_2 < s \le s_3$.*
- ***Intermediate-intervention** ($s_1 < s \le s_2$): The government selects the penalty level according to $p^* = 1 - s\lambda$, without providing messaging. This strategy induces separating equilibrium in which traditional agents comply ($\eta^* = \lambda$).*
- ***Zero-out** ($s_3 < s \le \overline{s}$): The government selects the penalty level according to $p^* = 1 - s\lambda + \beta\lambda$, without providing messaging. This strategy induces separating equilibrium in which all agents comply ($\eta^* = 0$).*

Threshold values and degenerate cases are detailed in the Appendix.

This proposition shows that the optimal policy exhibits a non-monotonic structure, with the penalty levels also varying non-monotonically with severity s. Figure 2 illustrates the optimal public policy, where the government chooses between two strategies: (1) **Message-based persuasion (Laissez-faire regime):** The government imposes no penalty ($p^* = 0$) but strategically uses differentiated messages to shape beliefs and induce targeted compliance behavior. (2) **Penalty-based enforcement (Intermediate-intervention and Zero-out regimes):** The government designs state-contingent penalties that fully disclose the severity of the pandemic and directly induce compliance among certain groups.

Figure 2 **Penalty and Messaging Strategies under Optimal Public Policy.**



To better understand each regime, we begin by examining the sources of misalignment between the government's public health objectives and individuals' incentives to comply. This misalignment arises from two key factors: individuals often fail to internalize the infection risks their social interactions impose on others, and socializing agents tend to place a higher value on interaction, making them less responsive to penalties than traditional agents. The degree of misalignment varies across different pandemic states. Anticipating these variations, the government strategically combines informational and regulatory instruments to align public behavior with its objectives in a cost-effective manner. By identifying the roots of misalignment and the rationale behind policy coordination, we can better interpret how the government adjusts its strategies in response to changes in both pandemic severity and public behavior, as elaborated in the following observation.

Observation 1. The government adopts message-based persuasion (laissez-faire regime) in both mild and moderate-to-high severity regions, while relying on penalty-based enforcement (intermediate-intervention and zero-out regimes) in moderate and high severity regions.

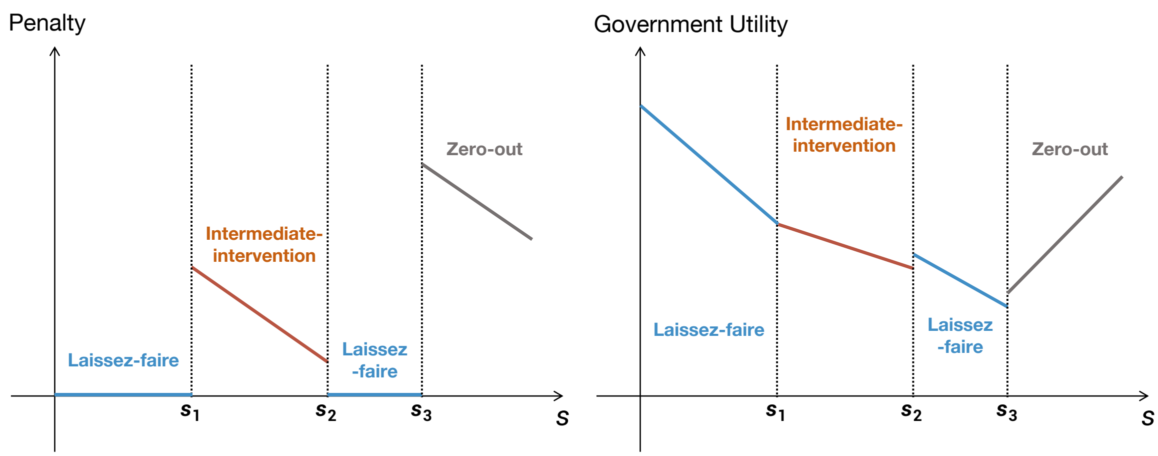
The laissez-faire regime is implemented in two disjoint intervals of pandemic severity: $s \leq s_1$ and $s_2 < s \leq s_3$. In mild pandemic states ($s \leq s_1$), the threat to public health is limited, and the government has little incentive to enforce compliance through costly interventions. Therefore, it refrains from imposing penalties ($p^* = 0$) and tolerates full violation ($\eta^* = 1$). A more strategic use of the laissez-faire regime emerges in the moderate-to-high severity range ($s_2 < s \le s_3$). Despite the increased severity, the government refrains from imposing penalties in this region. This is because its public health objectives are aligned with the incentives of traditional agents under moderate-to-high severity, as these agents are willing to comply voluntarily even without enforcement. Recognizing this alignment, the government avoids incurring enforcement costs and instead relies on messaging. It sends a signal that induces a perceived severity level of $\tilde{s} = (s_2 + s_3)/2 = 1/\lambda$, which is sufficient to induce compliance among traditional agents ($\eta^* = \lambda$) without the need for penalties. This outcome illustrates the strategic value of message-based persuasion: informative messaging provides a cost-effective tool for guiding public behavior by conveying information with fine granularity.

In contrast, the intermediate-intervention and zero-out regimes arise when misalignment between individual incentives and public health objectives becomes more pronounced, making the use of penalties necessary. The intermediate-intervention regime applies to moderate pandemic states ($s_1 < s \le s_2$), where traditional agents are unwilling to comply in the absence of enforcement. As the pandemic intensifies, the government prioritizes public health by targeting these more responsive agents while tolerating noncompliance from socializing agents to limit enforcement costs. In this regime, the government implements a state-dependent penalty ($p^* = 1 - s\lambda$), which allows individuals to accurately infer the true severity of the pandemic. Upon observing the actual severity and the corresponding penalty, traditional agents choose to comply ($\eta^* = \lambda$). The zero-out regime corresponds to severe pandemic states ($s_3 < s \le \overline{s}$), where ensuring full compliance ($\eta^* = 0$) becomes the overriding objective. In this region, socializing agents do not comply voluntarily due to the positive externalities of social interaction. To overcome this resistance, the government imposes a higher state-dependent penalty $p^* = 1 - s\lambda + \beta\lambda$, which is sufficient to induce compliance from both agent types ($\eta^* = 0$). We next provide a detailed analysis of how the optimal penalty and government utility evolve with pandemic severity s under the optimal policy.

COROLLARY 1. *Under the optimal policy, both the penalty and the government's utility exhibit a non-monotonic relationship with pandemic severity s. Specifically, the optimal penalty decreases in s within the intermediate-intervention and zero-out regimes. Government utility decreases in s in the laissez-faire and intermediate-intervention regimes, but increases in s in the zero-out regime.*

The government's objective is to balance infection costs (measured by $s\eta$) against enforcement costs (measured by ap) using distinct policy instruments. The resulting non-monotonic structure of the optimal penalty reflects a strategic response to two key factors: (i) endogenous infection risks driven by pandemic severity and (ii) heterogeneous behavioral responses from traditional and socializing agents. Figure 3(a) illustrates how the optimal penalty varies with pandemic severity. In the mild region ($s < s_1$), the government imposes no penalty and tolerates full violation, as enforcement is not cost-effective. However, as severity increases to a moderate level ($s_1 < s \leq s_2$), it becomes efficient to impose penalties in order to reduce infection risk caused by traditional agents. The government therefore applies a state-dependent penalty $p^* = 1 - s\lambda$. Notably, the optimal penalty decreases in s within this range, as higher severity naturally strengthens individuals' incentives to comply. Interestingly, in the moderate-to-high severity region, the government refrains from penalties and relies entirely on informative messaging. In this case, the higher perceived severity alone is sufficient to induce compliance among traditional agents, while enforcing compliance from socializing agents would be too costly. In severe pandemic states ($s_3 < s \leq \bar{s}$), public health becomes the overriding concern, and the government seeks to minimize infection costs by enforcing full compliance ($\eta^* = 0$). To achieve this, it imposes a higher state-dependent penalty.

Figure 3 Optimal Penalty and Government Utility as Functions of Pandemic Severity s.



(a) Optimal Penalty (b) Government Utility

The declining state-contingent penalties under the intermediate-intervention and zero-out regimes highlight the **dual role of penalties as both enforcement tools and informational signals**. State-dependent penalties allow the public to accurately infer the true severity of the pandemic. As severity increases, the government's objectives become more closely aligned with those of the public, since higher severity raises infection risks and naturally strengthens incentives to comply.

This endogenous shift reduces the need for costly enforcement, leading to a decline in the optimal penalty as severity s increases. In this way, the enforcement and signaling functions of penalties reinforce one another, thereby enhancing the overall cost-effectiveness of this policy instrument.

Figure 3(b) illustrates how government utility varies with pandemic severity. The utility decreases in s under both the laissez-faire and intermediate-intervention regimes. Although the level of social interaction (η^*) remains constant and penalties are non-increasing within each regime, rising severity leads to higher infection costs ($s\eta^*$). This increase outweighs any reduction in enforcement costs, resulting in a net decline in government utility. In contrast, utility increases in s under the zero-out regime. Since social interaction is fully eliminated in this region ($\eta^* = 0$), the resulting infection cost is minimized. Higher perceived severity enhances voluntary compliance among socializing agents, allowing the government to reduce the required penalty level and enforcement cost, thereby improving utility. It is worth noting that the discontinuous jumps in utility at the thresholds s_2 and s_3 are due to information pooling within the region (s_2, s_3). Further explanation of this discontinuity is provided in the Appendix.

Overall, these findings reveal a nuanced interplay among pandemic severity, behavioral responsiveness, and policy costs in shaping optimal interventions. They underscore the importance of adaptive, multi-instrument policy frameworks that balance public health objectives with institutional constraints during health crises. Furthermore, the results highlight the distinct functions of penalty-based enforcement and informational interventions, showing that their design and use depend critically on the alignment between government objectives and individual incentives.

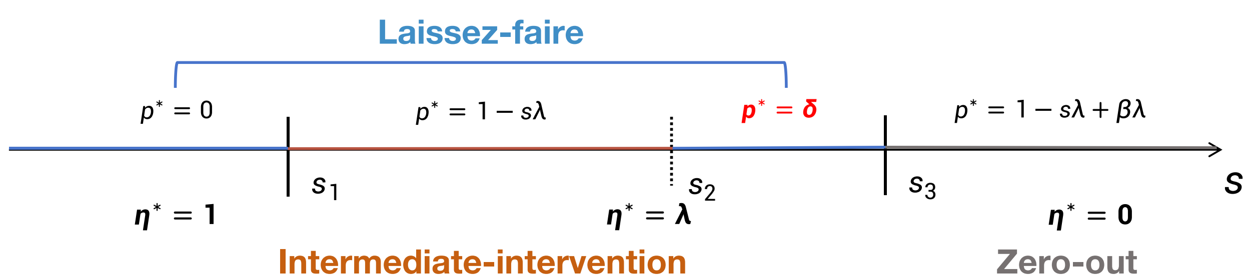
5.1. Message-Based Persuasion

This section further examines the dual role of penalties and the strategic value of messaging in public policy design. In the baseline model, the government commits to both penalty levels and messaging strategies. To isolate the informational value of messaging, we consider an alternative setting in which the government can commit only to penalties. In this case, penalties may not effectively fulfill their dual role as enforcement tools and informational signals simultaneously.

For example, under the laissez-faire regime described in Proposition 1, the optimal penalty remains constant over two disjoint intervals, specifically $p^* = 0$ for $s \in [0, s_1] \cup (s_2, s_3]$. In the baseline model, a zero penalty combined with message m_1 signals mild pandemic states ($s \in [0, s_1]$), while the same penalty paired with message m_2 signals moderate-to-high states ($s \in (s_2, s_3]$). In the absence of messaging, this separation is no longer feasible. The optimal policy in this case is shown in Figure 4. Compared to the benchmark case, the committed penalty in the range $(s_2, s_3]$

increases from zero to a strictly positive value $\delta > 0$. This adjustment is necessary for conveying information because a zero penalty in this region no longer allows the public to accurately infer the true pandemic state. Without access to messaging, the government must rely on marginal variations in penalties to maintain informational precision. However, such variation provides no additional benefit in regulating public behavior. The updated belief $\tilde{s} = (s_2 + s_3)/2 = 1/\lambda$ is already sufficient to induce full compliance from traditional agents ($\eta^* = \lambda$), so the added penalty δ does not further reduce social interaction. Instead, it imposes strictly higher enforcement costs (measured by $a\delta$), thereby reducing the government's expected utility. In this sense, the absence of messaging creates inefficiencies in the penalty's dual role as both an enforcement tool and an informational signal. Specifically, the government is sometimes forced to distort penalties for signaling purposes, even when such penalties serve no enforcement function. The following proposition formalizes the informational value of messaging in public policy by demonstrating its ability to eliminate such inefficiencies and improve both informational precision and cost-effectiveness.

Figure 4 **Optimal Public Policy in the Absence of Messages.**



Proposition 2 **(Value of Message-Based Persuasion)**. *When penalties alone cannot efficiently signal pandemic severity, the absence of messaging leads to strictly higher enforcement costs and strictly lower expected utility for the government.*

This result underscores the strategic value of communication in public policy, particularly when penalties alone cannot efficiently fulfill their dual role as enforcement tools and informational signals. Although our baseline model assumes full flexibility in setting penalties, real-world policy implementation is often constrained by legal, administrative, or logistical factors that limit not only the government's ability to pre-commit to a sufficiently rich set of penalty schemes, but also its ability to adjust penalties in a timely and state-contingent manner. In such cases, the value of communication becomes even more critical for conveying information with finer granularity and guiding public behavior more effectively. We provide an extended discussion of these constrained settings in Section B.2 of the Appendix.

5.2. Influence of Socializing Agents on Policy Design

This section further examines how the presence of socializing agents affects the design and performance of optimal public policy. Specifically, we investigate the impact of two key parameters: (i) the proportion of socializing agents in the population (λ) and (ii) their marginal utility derived from social interaction (β). Both parameters increase the utility associated with noncompliance, thereby exacerbating compliance challenges. However, we demonstrate that λ and β have distinct effects on policy formation.

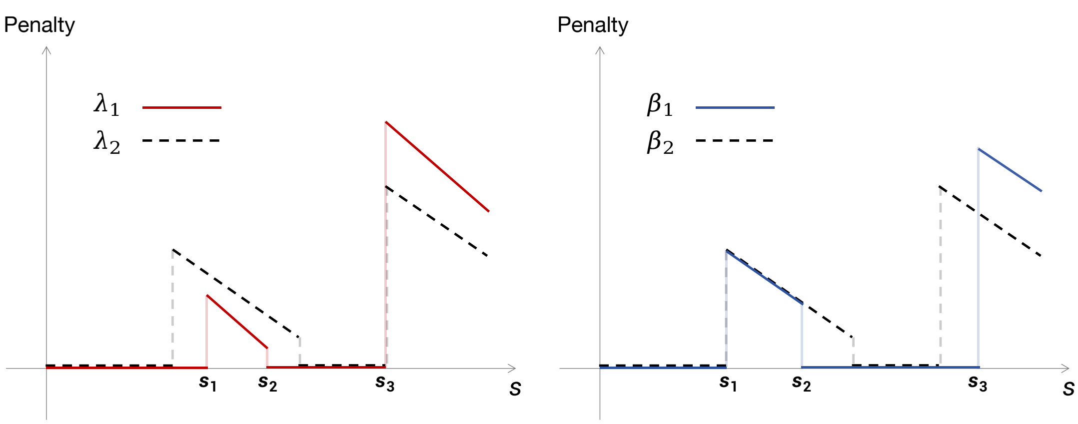
COROLLARY 2. *An increase in the proportion of socializing agents (λ) leads to the following effects:*

(a) The optimal penalty p^* decreases in the intermediate-intervention regime but increases in the zero-out regime.

(b) The government shifts from the intermediate-intervention regime to the laissez-faire regime in some moderate pandemic states, resulting in a shrinkage of the interval $(s_1, s_2]$.

(c) The government's expected utility declines.

Figure 5 How Socializing Agents Affect Optimal Penalty and Partitioning of Policy Regimes.



(a) $\lambda_1 > \lambda_2$ (b) $\beta_1 > \beta_2$

Figure 5(a) visualizes how the parameter λ affects the optimal penalty and the partitioning of policy regimes. Corollary 2(a) illustrates changes in the optimal penalty. Interestingly, in the intermediate-intervention regime, the government can impose a lower penalty to induce compliance from traditional agents. This occurs because a higher λ implies that socializing agents impose greater negative externalities on traditional agents, increasing their infection risk and thereby strengthening their incentive to comply. In contrast, under the zero-out regime, an increase in λ

amplifies the positive externalities of social interaction for socializing agents, requiring a higher penalty to induce full compliance. Corollary 2(b) illustrates how the boundaries between regimes shift with changes in λ. Notably, λ has no effect on government utility within the laissez-faire regime. However, in the intermediate-intervention regime, an increase in λ raises infection costs while reducing enforcement costs. The net effect is a decline in overall utility, which prompts a shift from the intermediate-intervention regime to the laissez-faire regime. Next, we examine the effects of changes in the parameter β.

COROLLARY 3. *An increase in the marginal utility of social interactions for socializing agents (β) leads to the following effects:*

(a) The optimal penalty p^* increases in the zero-out regime.

(b) The government shifts from the intermediate-intervention and zero-out regimes to the laissez-faire regime in some moderate and high pandemic states, leading to an expansion of the interval $(s_2, s_3]$.

(c) The government's expected utility declines.

Figure 5(b) visualizes how the parameter β affects the optimal penalty and the partitioning of policy regimes. Corollary 3(a) shows that a higher penalty is required within the zero-out regime, as β amplifies the positive externalities of social interaction for socializing agents, making compliance more difficult to achieve. Corollary 3(b) illustrates how the boundaries between regimes shift as β increases. A higher β makes strict enforcement less desirable, leading the government to tolerate a greater degree of noncompliance by socializing agents across a wider range of pandemic states. As a result, the regulatory focus shifts toward ensuring compliance from traditional agents, which raises the threshold s_3. Since the perceived severity in this interval remains fixed at $\tilde{s} = (s_2 + s_3)/2 = 1/\lambda$, a higher s_3 allows the government to further expand the information-pooling region by simultaneously lowering the lower bound s_2.

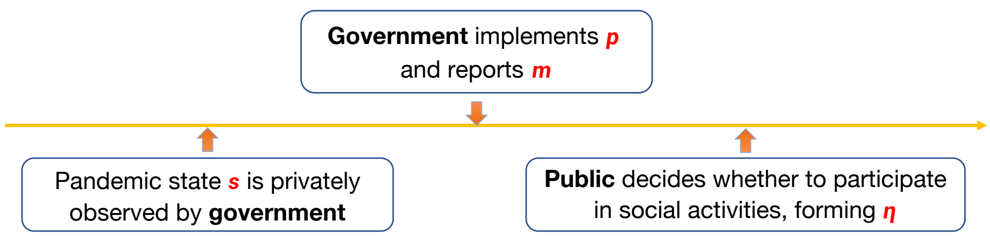
To summarize, while the overall impact of socializing agents on pandemic management is negative, they can generate indirect benefits by promoting compliance among traditional agents. This effect highlights the importance of carefully combining penalty-based and message-based interventions to account for agent heterogeneity and social externalities.

6. Extensions

6.1. The Value of Credibility

Our baseline analysis has focused on a scenario where the government has credibility, allowing it to commit to both penalties and messages when designing public policy. However, the government's inherent credibility can significantly reshape the dynamics of strategic communication. This section extends our analysis to a scenario in which the government lacks credibility. The government determines the penalty level and reports the message only after privately observing the severity of the pandemic. Consistent with prior research (Guo 2024), we approach this problem using a cheap-talk framework. However, a key distinction in our setting is that penalties directly impact the government's utility, whereas messages do not. This creates a hybrid communication model that combines elements of signaling (via penalties) and cheap talk (via messages).

Figure 6 Sequence of Events (No Credibility).



The revised sequence of events is presented in Figure 6. Consistent with recent literature in studying the problem of credibility in strategic communications (Lipnowski et al. 2022), we refer to this situation as *no credibility* and the basic model as *full credibility*. The Perfect Bayesian Equilibrium (PBE) is the standard solution concept in the case where the government lacks credibility (Lu 2024, Lu and Tomlin 2025). In this setting, the public's belief about the severity of the pandemic is consistent with the government's equilibrium strategy, and all parties make optimal decisions based on their own beliefs and the anticipated behavior of others. To reflect this, rewrite the government's utility function in Equation (5) as follows:

$$u(p,m|s) = -s\eta(\tilde{s}(p,m),p) - ap. \tag{7}$$

Under the no-credibility scenario, the government's policy, the public's response $\eta(\tilde{s},p)$, and the public's updated posterior belief $\mu(s|p,m)$ constitute a PBE if the following conditions hold:

- For any $s \in S$, the government chooses the combination (p,m) to maximize its utility $u(p,m|s)$.
- Given any $(p,m) \in P \times M$, the public optimizes their engagement decision, leading to the equilibrium $\eta(\tilde{s},p)$.
- On the equilibrium path, the public updates its belief $\mu(s|p,m)$ using Bayes' rule. Off the equilibrium path, the public retains its prior belief.

Compared to the benchmark case of full credibility, the key distinction under no credibility is that the government does not commit to a policy ex ante. Instead, it optimizes the policy pair (p,m) after observing the realized pandemic severity s. Consequently, unlike in the full credibility setting, the government's choices must satisfy incentive constraints for every realized s. As a result, the strategy space under no credibility is strictly limited.

Consider, for instance, the interval $(s_3,\overline{s}]$ in Figure 2, and let $\hat{s}_1 < \hat{s}_2$ be two severity states within this range. Under full credibility, the government commits to separating penalties $p^* = 1 - s\lambda + \beta\lambda$ and no message within this interval, resulting in $\eta^* = 0$. This means the government commits to choosing $(p^*(\hat{s}_1), m_0)$ when the actual state is $\hat{s}_1$ and $(p^*(\hat{s}_2), m_0)$ when the state is $\hat{s}_2$. However, under the no-credibility scenario, when the actual state is $\hat{s}_1$, the government always has an incentive to deviate and choose $(p^*(\hat{s}_2), m_0)$ rather than $(p^*(\hat{s}_1), m_0)$. This is because $p^*(\hat{s}_2)$ generates a lower enforcement cost than $p^*(\hat{s}_1)$, and the public response η^* remains unchanged after the deviation. Formally, we have:

$$u(p^*(\hat{s}_2), m_0|\hat{s}_1) > u(p^*(\hat{s}_1), m_0|\hat{s}_1). \tag{8}$$

Similar deviations can be observed in other states under penalty-based enforcement, where the government leverages the dual role of penalties and induces the same level of compliance using different penalty levels. The primary reason is that the government's utility function exhibits a *state-independent preference* structure: it seeks to reduce the equilibrium level of η^* regardless of the specific pandemic state s. Therefore, if multiple penalty levels can lead to the same compliance outcome (η^*), the government always deviates to the lowest penalty to minimize enforcement costs. We summarize this insight in the following proposition.

PROPOSITION 3. *The no-credibility government cannot implement the penalty-based enforcement described in Proposition 1, which restricts the set of implementable public policies and leads to strictly worse outcomes. Specifically, the optimal expected utility under full credibility strictly exceeds that under no credibility.*

The absence of credibility imposes stringent incentive constraints on the government, substantially narrowing the set of feasible policy strategies. These findings are consistent with the literature on strategic communication and the importance of credibility. For example, Kamenica and Gentzkow (2011) (Appendix, Section 1) and Lipnowski and Ravid (2020) (Theorem 2) emphasize that when the sender is credible, communication is constrained only by the receiver's incentives and

Bayes' rule. In contrast, without credibility, as in environments of informal or non-binding communication, the sender's own incentive constraints introduce additional inefficiencies and reduce the effectiveness of communication.

In our setting, penalty-based enforcement is implementable when the government's objectives align with those of traditional agents under the intermediate-intervention regime or with socializing agents under the zero-out regime. However, in the absence of credibility, additional incentive constraints intensify the misalignment between the government and the public. As a result, such enforcement becomes infeasible. This highlights the essential role of credibility in public policy design. When the government is perceived as credible, it can design policies more flexibly and adaptively, better aligning its objectives with public incentives and achieving more effective outcomes. In contrast, the absence of credibility imposes binding incentive constraints that exacerbate the misalignment between the government and the public, thereby narrowing feasible policy options and reducing overall policy effectiveness.

6.2. Alternative Policy Objectives

In addition to public health, sustaining economic growth is a key priority for the government in pandemic management. This section extends our model by integrating economic growth goals into pandemic management. Compared to the utility function defined in Equation (5), the revised utility function is expressed as:

$$\dot{u}_g(s) = (e - s)\eta - ap, \tag{9}$$

where e represents the government's weight on economic growth. This revised model captures a new trade-off in designing public policy. When the pandemic is mild ($s < e$), the government places priority on economic growth by promoting the level of social interactions η. Conversely, when the pandemic becomes severe ($s > e$), public health is the primary concern, and the government intends to limit social interactions by reducing η. The following proposition characterizes the government's optimal public policy when economic growth considerations are taken into account.

PROPOSITION 4. *There exist four unique thresholds* $(\dot{s}_0, \dot{s}_1, \dot{s}_2, \dot{s}_3)$ *that define the optimal public policy across three distinct regimes:*

- ***Laissez-faire*** *($s \leq \dot{s}_1$): The government imposes no penalty ($p^* = 0$) but adopts different messaging strategies across sub-intervals:*
  - *—For $0 < s \leq \dot{s}_0$ and $\dot{s}_2 < s \leq \dot{s}_3$, the government sends messages $\dot{m}_1$ and $\dot{m}_2$, respectively.*
  - *—For $\dot{s}_0 < s \leq \dot{s}_1$, the government discloses full information by sending separating messages.*

- ***Intermediate-intervention*** *and* ***zero-out****: These regimes remain the same as those described in Proposition 1, and apply to the intervals $\dot{s}_1 < s \leq \dot{s}_2$ and $\dot{s}_3 < s \leq \overline{s}$, respectively.*

The updated thresholds satisfy $\dot{s}_1 > \dot{s}_0 > s_1$ and $\dot{s}_3 > s_3$.

Figure 7 Optimal Public Policy in the Presence of Economic Consideration.

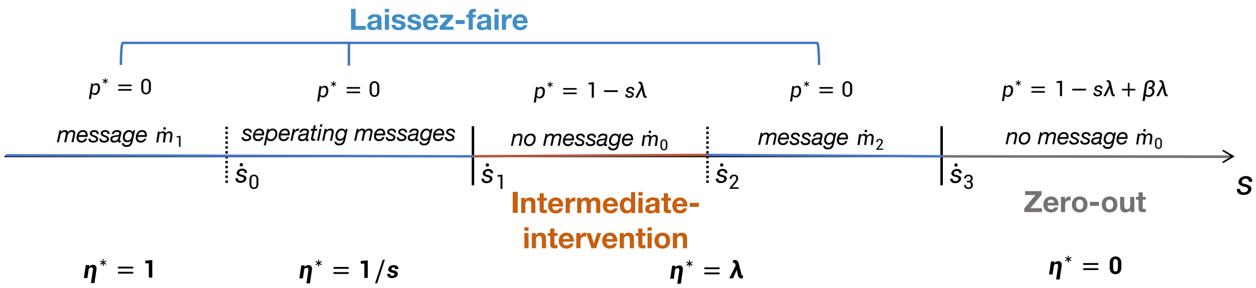
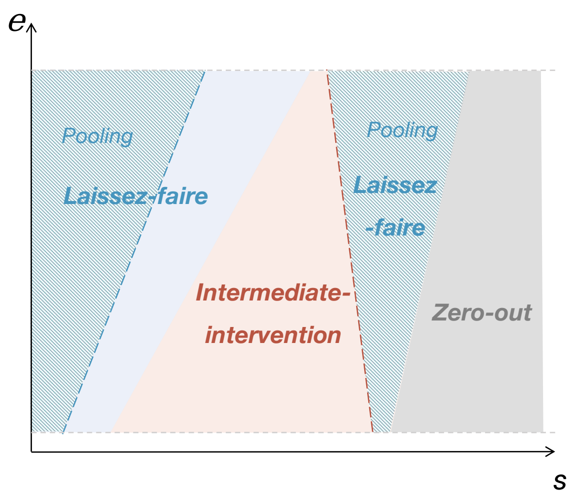


Figure 7 presents the revised public policy. Compared to the baseline model, two key differences emerge. First, the government reduces the overall level of penalties to support a higher equilibrium level of social interactions. Specifically, since $\dot{s}_1 > \dot{s}_0 > s_1$, the laissez-faire regime ($p^* = 0$) extends over a broader range of pandemic states. Moreover, with $\dot{s}_3 > s_3$, the incentive for enforcing full compliance ($\eta^* = 0$) is weakened. Second, within the expanded laissez-faire regime, a new interval with separating messages, $(\dot{s}_0, \dot{s}_1]$, emerges. This allows the public to accurately infer the severity of the pandemic. In this regime, the government relies solely on message-based strategies to manage compliance and balance competing objectives. For mild severity levels ($0 \leq s < \dot{s}_0$), where economic growth is prioritized over health protection, the government pools information to encourage full social interaction ($\eta^* = 1$) across a wider range of states. As severity increases to $s \in (\dot{s}_0, \dot{s}_1]$, the government shifts to separating messages to induce partial compliance from traditional agents. This approach is favored over penalties due to its cost-effectiveness. Within this separating interval, a fraction of traditional agents choose to comply, resulting in $\eta^* = 1/s$. This equilibrium compliance level decreases with severity, highlighting the role of messaging in conveying information with fine granularity. Building on this revised policy framework, we next examine how the parameter e influences the structure of the optimal policy, offering deeper insights into the role of economic growth in policy design. The findings are summarized in the following corollary.

Corollary 4. *As the weight placed on economic growth (e) increases, the government increasingly relies on message-based persuasion (laissez-faire regime) across a broader range of pandemic states.*

Figure 8 illustrates how increasing emphasis on economic growth reshapes the structure and orientation of public policy. In the baseline model, misalignment between government objectives and individual incentives, caused by infection externalities and heterogeneous preferences for social interaction, necessitates costly penalty-based interventions in addition to informational tools. As the government places greater weight on economic outcomes and aims to promote social activity, its objectives become more closely aligned with individual incentives. This reduces the reliance on punitive enforcement and increases the effectiveness of message-based persuasion, thereby expanding the laissez-faire regime across a wider range of pandemic severities. In particular, when $s < e$, the government may prefer a higher level of social interaction than individuals, who remain cautious due to infection concerns. In such cases, persuasive communication becomes the only viable policy tool. The government strategically withholds information to reduce perceived severity and encourage full participation ($\eta^* = 1$). This is reflected in the expansion of the first pooling region in the figure as e increases. These findings show how governments can adaptively shift between regulatory and informational instruments to balance public health goals with economic priorities. This adjustment reflects real-world patterns, where growing emphasis on economic recovery often leads to a transition from strict enforcement to more flexible, communication-based strategies.

Figure 8 **How Economic Growth Influences Policy Formation.**



6.3. Heterogeneous Agents

Our baseline model considers two discrete types of agents, with socializing agents sharing a homogeneous preference for social interaction. In this section, we generalize the model by allowing the preference parameter β to vary continuously over the support $[\underline{\beta}, \overline{\beta}]$, with a cumulative distribution function $G(\cdot)$. Accordingly, we adjust the support of the pandemic state s from $[0, \overline{s}]$ to $[\underline{s}, \overline{s}]$ to ensure consistency in the extended framework. This extension allows us to examine the robustness of our main results, particularly the interaction between different policy levers. The revised utility $\ddot{u}$ of an individual agent is given by:

$$\ddot{u} = \begin{cases} 1 - p - s\eta + \beta\eta, & \text{if } A = 1, \\ 0, & \text{if } A = 0. \end{cases} \tag{10}$$

We can define a threshold β^* that separates agents into two groups. An agent will violate social restrictions if and only if $\beta > \beta^* = s - \frac{1-p}{\eta(\beta^*)}$. The expected level of social interaction is then given by $\eta(\beta^*) = 1 - G(\beta^*)$. We can derive the threshold β^* by solving:

$$1 - p - s(1 - G(\beta^*)) + \beta^*(1 - G(\beta^*)) = 0. \tag{11}$$

A key challenge in this extended model arises from the inclusion of positive externalities ($\beta\eta$) in the utility function. Unlike models that consider only negative externalities, this formulation can lead to non-monotonicity in $\ddot{u}(\beta^*)$, meaning that β^* may not be unique, potentially allowing for mixed-strategy equilibrium. To ensure a pure strategy, we impose the following assumption:

Assumption 1. *The agent's utility $\ddot{u}(\beta^*)$ increases monotonically for any $\beta^* \in [\underline{\beta}, \overline{\beta}]$.*

In models with purely negative externalities, this assumption typically holds naturally (see Proposition 1 in de Véricourt et al. (2021) and Proposition 1 in Guo (2024)). In the context of pandemic management, this assumption is also reasonable and aligns with real-world observations: agents with sufficiently high social interaction tendencies ($\beta > \beta^*$) will always choose to engage in social activities. Without this assumption, unrealistic scenarios may arise in which agents with intermediate β choose to engage in social interactions while those with even higher β comply with restrictions. For analytical tractability, we assume that both β and s follow uniform distributions over their respective supports, and without loss of generality, we set $\underline{\beta} = 0$. In equilibrium, the level of social interaction from Equation 6 is revised as follows:

$$\ddot{\eta}^*(s, p) = \begin{cases} 1, & p < 1 - s, \\ \frac{\sqrt{(s-\overline{\beta})^2 + 4\overline{\beta}(1-p)} + \overline{\beta} - s}{2\overline{\beta}}, & 1 - s \leq p < 1, \\ 0, & p \geq 1. \end{cases} \tag{12}$$

Compared to the basic model, the key difference emerges when the perceived severity and penalty are at intermediate levels. In the basic model, the presence of socializing agents with a fixed β

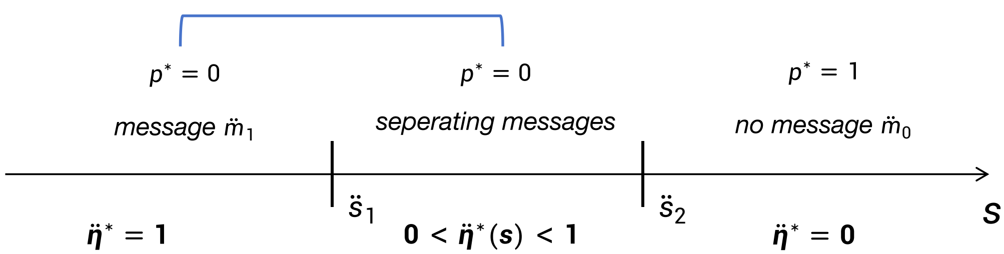
leads to a discontinuous drop from λ to 0 in terms of the equilibrium social interaction level. In contrast, in the revised model, the equilibrium $\ddot{\eta}^*$ gradually decreases as s and p increase, making it consistently state-dependent. These changes in the equilibrium level of social interaction, in turn, influence the government's optimal public policy. We next present the optimal policy in this extended framework.

PROPOSITION 5. *There exist two unique thresholds $(\ddot{s}_1, \ddot{s}_2)$ that determine the government's optimal public policy across three distinct regimes:*

- *For $s \le \ddot{s}_1$: The government imposes no penalty ($p^* = 0$) and reports a message $\ddot{m}_1$. All agents engage in social interactions ($\ddot{\eta}^* = 1$).*
- *For $\ddot{s}_1 < s \le \ddot{s}_2$: The government continues to impose no penalty ($p^* = 0$) but switches to separating messages. A certain fraction of agents engages in social interactions, with equilibrium behavior given by $\ddot{\eta}^* = \frac{\overline{\beta}+\sqrt{4\overline{\beta}+(s-\overline{\beta})^2}-s}{2\overline{\beta}}$.*
- *For $\ddot{s}_2 < s \le \overline{s}$: The government enforces a uniform penalty $p^* = 1$ and reports no additional messages. All agents comply with social restrictions ($\ddot{\eta}^* = 0$).*

The message $\ddot{m}_1$ differs from all separating messages reported in the interval $(\ddot{s}_1, \ddot{s}_2]$.

Figure 9 **Penalty and Messaging Strategies under Optimal Public Policy (Continuous β).**



This policy is illustrated in Figure 9. Similar to Proposition 1, the optimal public policy follows a three-regime structure. In extreme pandemic states, the government commits to either no penalty ($p^* = 0$) or strict enforcement ($p^* = 1$), leading to full engagement or full compliance among agents, respectively. The key difference arises in intermediate pandemic states, where the government still refrains from imposing penalties but instead employs separating messages. Upon receiving these messages and learning the true pandemic state, only a fraction of agents choose to engage in social interactions. This is driven by the gradual nature of the public's response to penalties and perceived pandemic severity (shown in Equation 12). Moreover, an important insight is that messaging continues to serve as an effective tool for conveying information with fine granularity. In summary, while incorporating a continuous distribution of β alters individual responses and policy choices, the interaction between policy instruments remains effective in guiding public behavior.

7. Conclusion

This paper investigates how governments can design optimal public health policies that integrate both physical or monetary penalties and strategic communication to alert the public amid uncertain pandemic severity. Compared with traditional agents in existing literature, we introduce socializing agents—individuals who place high value on social interaction and are more likely to disregard public health guidelines. By accounting for this heterogeneity in social behavior, we show that the government's optimal policy follows a nonmonotonic pattern with respect to pandemic severity. To manage the fundamental trade-off between protecting public health and minimizing enforcement costs, the government strategically alternates between two instruments: messages (strategic persuasive communication) and penalties (administrative or legal enforcement).

We find that messages are most effective when pandemic severity is either mild or moderate-to-high. This is because such communications work best when the misalignment between government objectives and individual incentives is limited. In these cases, the government can rely on costless, finely calibrated messages to guide public behavior effectively. In contrast, penalties become necessary when the misalignment of incentives is substantial. Notably, we identify a dual role for state-contingent penalties: while higher penalties directly enhance compliance by raising the cost of violating public health measures, they also signal the severity of the pandemic, thereby promoting voluntary adherence. This self-enforcing mechanism allows the government to reduce penalty levels as severity increases. Furthermore, we extend the basic model to examine the value of credibility and the impact of competing policy objectives on policy design. Overall, our findings highlight how the strategic coordination of messaging and penalties can serve as complementary tools in the development of flexible and effective public health policies.

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