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Strategic Information Disclosure to be imitated under Informational and Payoff Externality

Young-Ro Yoon
Wayne State University

Abstract

This paper attempts to provide an answer to the question of why agents in competition are often willing to disclose private information. I present a simple model demonstrating that information can be disclosed intentionally to induce imitation. In the model, three players who are heterogeneous in terms of information quality forecast the unknown true state. The payoffs, which depend on the correctness of the forecast, are shared if players' forecasts are identical. The result shows that, in a risk-dominant equilibrium, neither the most-informed nor the least-informed player discloses his information. On the other hand, the mediocre less-informed player is willing to disclose information, as long as the quality of his information is relatively low compared to that of the most-informed player, in order to induce imitation. By inducing the least-informed player to make an identical forecast, the mediocre less-informed player can avoid the worst case in which he is penalized alone. This result suggests that a revealing equilibrium can arise in a setting with multiple players without asymmetry in the payoff structure or a costly waiting option, in contrast to the two player case that has been widely adopted in the literature.

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Contact: Young-Ro Yoon - yoonyr@wayne.edu.
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1 Introduction

In this paper, I study the topic of strategic disclosure of information in a competitive environment. In practice, agents or firms in competition often take actions disclosing private information to competitors. For example, some rating agencies announce their rating earlier than others, even though it reveals private information about their evaluation. A firm's preannouncement of a new product or upcoming innovation discloses the private information of what it is preparing now for future competition. Given that rating agencies can choose when to announce their ratings and firms are not required to make a preannouncement, these disclosures of private information represent a strategic choice. In that case, why do agents disclose private information voluntarily? This is the main question addressed in this paper and I suggest that the incentive to induce imitation can be an answer under certain conditions.

I present a model where three players, who are heterogeneous in information quality, forecast the unknown true state. Each player's information quality is public information. Henceforth, "action" refers to the announcement of a forecast. This paper departs from the two player case that has been widely adopted in the literature and finds that considering multiple players may yield a different equilibrium. As the simplest case, I consider three players. Out of three players, only two players observe their own private signal, which is informative but not perfect, about the true state. The payoff structure of the reward for a correct forecast and the penalty for a wrong forecast is symmetric. The reward and penalty are shared, depending on the realized true state, if players' actions are identical. Players decide the timing of their action endogenously. As there is no cost for delaying action and players recognize that action reveals their own private signal, the decision on the timing of their action is no more than a decision on the disclosure of private information. If an agent takes action without a delay even when the delay is not costly, it implies that he is willing to disclose his private signal.

The result shows that, in a risk-dominant equilibrium, the most-informed player delays his action to prevent his signal from being revealed to other less-informed players. He has strong confidence in his signal and, in order to earn the reward alone, does not want to share this private information. The uninformed player also delays his action to infer the more-informed players' signals. On the other hand, the mediocre less-informed player does not use a waiting option and is willing to disclose information by taking action without delay as long as the precision of his signal is relatively low compared to that of the most-informed player. He does this in order to induce the uninformed player's identical action, which is supported by the uninformed player's imitation. In this way, those two players can avoid the worst case in which each of them is penalized alone. Given that herding toward an action based on the most precise information is not possible, this is their strategic choice. In this way, considering more players creates a new channel whereby strategic interactions to utilize the payoff externality arise among the less-informed players.

This paper is in line with Yoon (2009) and Yoon (2017) that consider the topic of strategic information disclosure with a similar setting. Yoon (2009) considers the two player case. In that model, for the revealing equilibrium to exist (i.e. for information to be disclosed in equilibrium), delaying action must be costly. Moreover, it arises only as a mixed strategy equilibrium.[2] Yoon also (2017) considers the two player case, but pays attention to the role of asymmetry in the payoff structure of reward and penalty. In

[2] In Yoon (2009), if no cost is imposed for delaying action, both heterogeneous players always delay their actions. The less-informed player uses a waiting option for learning (inference of more-informed player's private information) and the more-informed player does so to prevent the less-informed player's learning.

that model, if the information quality (precision of signal) is public information, asymmetry in the payoff structure biased toward penalty is necessary for the revealing equilibrium to exist. Given a symmetric reward and penalty, a revealing equilibrium never arises.[3] In this model, however, I consider the case of more than two players. The purpose is to check whether considering multiple players creates a new channel which cannot be analyzed in the conventional setting of two players. I show that, if more than two players are considered, while the information quality is public information, i) a costly waiting option or ii) asymmetry in reward and penalty is not necessary for the revealing equilibrium to exist. Moreover, in this model, it arises as a pure equilibrium. This is due to the strategic interactions among the less-informed players that lead them to utilize the payoff externality, which yields an equilibrium where the less-informed player with weak information reveals his signal. This result proposes a coalition among the less-informed players, who minimize their risk by taking the same action. Given that the most precise information is not disclosed, it is their rational strategic choice.

This paper is related to a large literature of herding which explores how agents respond to the information inferred from others' actions. (See Banerjee (1992), Bikhchandani, Hirshleifer and Welch (1992), Gale (1996), and Scharfstein and Stein (1990) as seminal works.) However, in these models, the timing of action is given exogenously and the leaders' actions are supposed to be observed by the follower. Hence, the analysis of how that information, which the follower can utilize for herding, is generalized is absent. This model studies how information toward which herding arises is strategically generated.

This model is also related to the literature on endogenous timing of action games. Chamley and Gale (1994) and Zhang (1997) discuss strategic delays, but in a setting where only an informational externality is present. In this model, both informational and payoff externalities are present. Choi (1997) and Frisell (2003) are more closely related to this paper in that they also use a framework of an endogenous timing of action game to study some particular cases in which both informational and payoff externalities are present. Choi (1997) considers technology adoption. In his model, no player has private information about the unknown true state and any player's choice reveals the true state immediately. Hence, each player has an incentive to delay his choice to make the other do the experiment on his behalf. In this model, the strategic choice on the timing of action is related to the disclosure of informed players' private information, not to the disclosure of the unknown true state. Frisell (2003) considers a case in which two firms select a product design and decide when to enter a market. In his model, whether making identical choices causes a positive or negative externality is given exogenously. Meanwhile, in my model, it is determined endogenously depending on each player's information quality.

Finally, Gallini (1984), Conner and Rumelt (1991) and Conner (1995) are related to this paper in that, in different settings, they deal with the strategic advantage from being imitated by a competitor. Gallini (1984) suggests that licensing can be used as a tool to allow imitation, thus preventing rivals from engaging in R&D activity leading to better technology. Conner (1995) and Conner and Rumelt (1991) propose that allowing other firms' imitation can be a dominant strategy if a positive network externality is present. In these models, information quality does not play a role. Hence, the question of how information quality affects the strategic decision on the disclosure of information is not addressed.

The rest of this paper is organized as follows. Section 2 introduces the model. Section 3 studies how the equilibrium of action timing is characterized endogenously. Section 4 concludes.

[3] Another contribution of Yoon (2017) is that the case where the information quality is private information is analyzed. Considering the private information case in the current model is beyond the scope of this paper.

2 Model

There are three players M, L, and U, $i \in \{M, L, U\}$, whose job is to announce a forecast about the unknown true state of the forthcoming period. Henceforth, "action" refers to the announcement of a forecast. The true state is $w \in \{H, L\}$ and those are mutually exclusive. The prior probability of each state is $\Pr(w = H) = \Pr(w = L) = \frac{1}{2}$. Before taking action, M and L observe their own private signal $\theta_k \in \{h, l\}$, $k \in \{M, L\}$, which is correlated with the true state. The draws of their signals are conditionally independent given the true state. The signal θ_k partially reveals information about the true state in the following way

$$\begin{aligned} \Pr(\theta_k = h|w = H) &= \Pr(\theta_k = l|w = L) = p_k \\ \Pr(\theta_k = h|w = L) &= \Pr(\theta_k = l|w = H) = 1 - p_k \end{aligned}$$

where $p_k \in \left(\frac{1}{2}, 1\right)$. Here, p_k measures the precision of player k's signal θ_k, so it can also be interpreted as the information quality. As p_k approaches $\frac{1}{2}$, his signal becomes less informative. As it approaches 1, his signal becomes more informative. As $\frac{1}{2} < p_k < 1$, the signal θ_k is informative, but not perfect. M and L are heterogeneous in terms of the precision of θ_k. Without loss of generality, it is assumed that M's signal is more precise than L's signal, i.e., $p_L < p_M$. On the other hand, U has no chance to observe his own signal correlated with the true state. U knows that M and L are partially informed about the true state and p_k is public information. In this setting, M represents the most-informed player, L represents the less-informed player, and U represents the uninformed player.[4]

Each player i decides when to act and how to act, i.e., $\{a_i, t_i\}$. Here, $a_i \in \{h, l\}$ denotes i's announcement of forecast: $a_i = h$ ($a_i = l$) denotes that i's forecast is $w = H$ ($w = L$). Also $t_i \in T = \{t_1, t_2\}$ denotes i's timing of action. Player i has two rounds during which he takes an irreversible action only once. If i takes action in round 1 (round 2), it is denoted by $t_i = t_1$ ($t_i = t_2$). If actions are taken sequentially, i.e., $t_i \neq t_{-i}$, the follower can observe the leader's action. If actions are taken simultaneously, i.e., $t_i = t_{-i}$, i cannot observe $-i's$ action.

Each player's ex-post payoff is defined by $\pi_i(a_i, a_{-i}, w)$ where π_i is determined after the realization of true state w conditional on a_i and a_{-i} as follows:

$$\pi_i(a_i, a_{-i}, w) = \begin{cases} \frac{\gamma}{n+1} & \text{if } a_i = w \\ \frac{-\gamma}{n+1} & \text{if } a_i \neq w \end{cases} \tag{1}$$

where $\gamma > 0$ and $n \in \{0, 1, 2\}$ is the number of other players who acted identically with i. Here, $a_i = w$ ($a_i \neq w$) denotes that i's forecast turns out to be right (wrong). The important feature of this payoff structure is that $\frac{\partial \pi_i(a_i, a_{-i}, w)}{\partial n} < 0$ if $a_i = w$ and $\frac{\partial \pi_i(a_i, a_{-i}, w)}{\partial n} > 0$ if $a_i \neq w$. That is, the correctness of a_i determines whether other players' identical forecasts cause a negative or positive payoff externality. However, there is uncertainty because the true state is revealed after a_i is announced.

The timing of the game is as follows.

T1) The ex-post payoff structure and M's and L's information quality p_k are announced.
T2) The informed player, $k \in \{M, L\}$, observes his private information $\theta_k \in \{h, l\}$.
T3) Each player $i \in \{M, L, U\}$ announces $a_i \in \{h, l\}$ during $t_i \in \{t_1, t_2\}$.

[4] I can also consider a setting in which U is an informed player with the least precise signal. Considering the uninformed player as the least-informed player yields qualitatively equivalent results while simplifying the analysis.

T4) After two rounds are over, the true state w is revealed and i earns the payoff $\pi_i(w, a_i, a_{-i})$.

The following definitions are used throughout this paper.

Definition 1 *We say that* k *follows the signal truthfully if* $a_k = \theta_k$.

Definition 2 *Herding: For* $k \in \{M, L\}$ and $i \in \{M, L, U\}$, *suppose that* $t_k = t_2$ and $t_i = t_1$ $(k \neq i)$. *When* $\theta_k \neq a_i$, *if* $a_k = a_i$, *we say that* k *exhibits herding.*

Definition 3 *Imitation: For* $k \in \{M, L\}$, *suppose that* $t_k = t_1$ and $t_U = t_2$. *If* $a_U = a_k$, *we say that U imitates k's action.*[5]

3 Analysis

3.1 Procedure

The goal of the analysis is to characterize the equilibrium of when to act and how to act, $\{a_i, t_i\}$. Each player should make those decisions before t_1 starts. The analysis proceeds as follows.

Step 1) We derive each player's best responses regarding how to act, a_i, contingent on $t_i, t_{-i} \in \{t_1, t_2\}$: i) for $k \in \{M, L\}$, whether to follow θ_k or not, ii) for U, whether to imitate or deviate from a_k if it is observable.[6]

Step 2) Using the best responses derived in step 1), we derive each player's ex-ante expected payoffs contingent on $t_i, t_{-i} \in \{t_1, t_2\}$.

Step 3) Using the ex-ante expected payoffs derived in step 2), we characterize i's equilibrium strategy of when to act, $t_i \in \{t_1, t_2\}$. How a_i is realized given $t_i, t_{-i} \in \{t_1, t_2\}$ follows the best response derived in step 1).

In steps 1 and 2, calculating the ex-ante expected payoffs contingent on $t_i, t_{-i} \in \{t_1, t_2\}$ is essential due to the payoff and informational externality. While the forecast a_i matters due to the payoff externality, it is also related to the informational externality. The signal θ_k can be inferred if a_k is observable, which is determined by t_k, t_{-k}.

The equilibrium concept we adopt is the (weak) perfect Bayesian Nash equilibrium. The two informed players, $k \in \{M, L\}$, observe their own private signal θ_k. When the timing of action is sequential and k takes action in t_1, given a_k, whether $a_k = \theta_k$ or $a_k \neq \theta_k$ cannot be verified. Hence, in deriving the follower's best response, his belief for $a_k = \theta_k$ matters. In equilibrium, the follower's belief for $a_k = \theta_k$ should be consistent with the leader k's equilibrium strategy. That is, the simultaneous decision on t_i should foresee the case of sequential actions in which the concepts of sequential rationality and consistency are required in the analysis.

The analysis of those three steps is tedious because analogous procedures are repeated for all players. For brevity, we pass over the detailed analysis, and instead present the main results of each step and focus on providing an intuitive explanation.[7]

[5] I differentiate the concepts of imitation and herding because U has no private signal from which to deviate.

[6] If a_k is observable, it is obvious that the strategy to utilize a_k based on the informative signal dominates the strategy to randomize a_U while ignoring a_k. If a_k is not observable, U is supposed to randomize a_U.

[7] The ex-ante expected payoffs used in deciding $t_i \in \{t_1, t_2\}$ are described on page 6.

3.2 Each player's best responses

Each player's best responses contingent on $t_i, t_{-i} \in \{t_1, t_2\}$ are as follows.

Lemma 1 (M's best response)
M's best response is always to follow his signal truthfully.

Lemma 2 (U's best response)
1) If $t_U = t_1$, he randomizes his action.
2) Suppose that $t_U = t_2$.
2-1) If $t_k = t_1$ and $t_{-k} = t_2$, he imitates t_k.
2-2) If $t_M = t_L = t_1$, he imitates a_M.

Lemma 3 (L's best response)
1) If $t_L = t_1$, he follows his signal truthfully.
2) Suppose that $t_L = t_2$.
2-1) Given that $t_M = t_1$, if $\theta_L = a_M$, he follows his signal truthfully, but if $\theta_L \neq a_M$, he exhibits herding toward a_M.
2-2) Given that $t_M = t_2$ and $t_U = t_1$, if $\theta_L = a_U$, he follows his signal truthfully. However, when $\theta_L \neq a_U$, if $p_M - 7p_L + 3 > 0$, L exhibits herding toward a_U and if $p_M - 7p_L + 3 < 0$, he follows his signal truthfully.

Considering that i) M is the most-informed player and ii) U observes no private informative signal, most parts of these best responses are intuitive. There are two points worthy of note. First, as $a_k = \theta_k$ when $t_k = t_1$, θ_k is inferred perfectly if $t_k = t_1$. Thus, the informational externality is present. This also implies that if $t_k = t_1$, k acts so while anticipating that other players infer θ_k. Second, when only U takes action in t_1, L's best response in t_2 is affected by a_U, even though L knows that a_U has no information value about the true state. This is due to the payoff externality. Although a_U is not correlated with the true state, if it turns out that $a_U = a_M = w \neq a_L$, this is the worst case to L because L is penalized alone. In this case, U's identical mistake could create a positive payoff externality because the penalty could be shared. That is, when L has no chance to exhibit herding toward a_M, if L is concerned about the case where $a_L \neq w$, he would like to utilize the payoff externality. Which strategy is selected depends on the relative precision of θ_L. The condition that $p_M - 7p_L + 3 > (<)\, 0$ corresponds to the case where θ_L is relatively imprecise (precise). Hence, if his relative information quality is low, L exhibits herding toward a_U even though he knows that a_U has no information value. Otherwise, L follows his signal truthfully while ignoring a_U because he is relatively confident in his signal.

3.3 Equilibrium

Using each player's best responses, I derive each player's expected payoffs contingent on $t_i, t_{-i} \in \{t_1, t_2\}$. Note that players decide when to act before t_1 starts. That is, i has no chance to observe a_k and infer θ_k when he decides t_i $(i \neq k)$. Hence, in deriving the expected payoffs, the belief of the informed player k should be $\Pr(w, \theta_{-k} | \theta_k)$. In the case of U, it is $\Pr(w, \theta_M, \theta_L)$. How a_i and a_{-i} are realized follows Lemmas 1, 2 and 3.

Then, k's ex-ante expected payoffs are derived from

$$E\pi_k = \sum_{w\in\{H,L\}} \sum_{\theta_{-k}\in\{h,l\}} \Pr(w,\theta_{-k}|\,\theta_k)\pi_i\left(a_k, a_{-k}, a_U, w\right) \tag{2}$$

or

$$E\pi_k = \frac{1}{2} \sum_{w\in\{H,L\}} \sum_{\theta_{-k}\in\{h,l\}} \Pr(w,\theta_{-k}|\,\theta_k) \left(\sum_{a_U\in\{h,l\}} \pi_i\left(a_k, a_{-k}, a_U, w\right) \right) \tag{3}$$

Here, (2) corresponds to the case in which U can observe a_k, so a_U is determined by a_k. (3) corresponds to the case in which U cannot observe a_k, so the randomization of a_U should be conjectured.[8]

U's ex-ante expected payoffs are derived from

$$E\pi_U = \sum_{w\in\{H,L\}} \sum_{\theta_M\in\{h,l\}} \sum_{\theta_L\in\{h,l\}} \Pr\left(w,\theta_M,\theta_L\right)\pi_U\left(a_k, a_{-k}, a_U, w\right) \tag{4}$$

If a_k is observable, a_U depends on a_k. Otherwise, a_U is randomized and $E\pi_U(a_U = h) = E\pi_U(a_U = l)$.

In (2) and (3),

$$\Pr\left(w,\theta_{-k}|\,\theta_k\right) = \frac{\Pr\left(\theta_k,\theta_{-k}|\,w\right)\Pr(w)}{\sum_w \left[\Pr\left(\theta_k|\,w\right)\Pr(w)\right]} = \frac{\Pr\left(\theta_k|\,w\right)\Pr\left(\theta_{-k}|\,w\right)}{\sum_w \Pr\left(\theta_k|\,w\right)} \tag{5}$$

and, in (4),

$$\Pr\left(w,\theta_M,\theta_L\right) = \Pr\left(\theta_M,\theta_L|\,w\right)\Pr(w) = \Pr\left(\theta_M|\,w\right)\Pr\left(\theta_L|\,w\right)\Pr(w) \tag{6}$$

because, i) for $w \in \{H, L\}$, the prior belief is $\Pr(w) = \frac{1}{2}$ and ii) the draws of signals are conditionally independent given the true state.

Each players's expected payoffs derived from (2), (3), and (4) are summarized in the appendix. Then, it is straightforward to derive the pure strategy Nash equilibrium of the action timing.

Proposition 1

1) Suppose $p_L < \frac{3}{4}$. Then, $\exists p^*$ such that if $p_M < p^*$, $(t_L, t_M, t_U) = (t_2, t_2, t_2)$ and (t_2, t_2, t_1) and if $p^* < p_M$, $(t_L, t_M, t_U) = (t_1, t_2, t_2)$ and (t_2, t_2, t_1).

2) Suppose $p_L > \frac{3}{4}$. Then, $\forall p_M \in (p_L, 1)$, $(t_L, t_M, t_U) = (t_2, t_2, t_2)$ and (t_2, t_2, t_1).

Here, $p^* = \frac{4p_L-1}{2}$.

If i) $p_L < \frac{3}{4}$ and $p_M < p^*$ or ii) $p_L > \frac{3}{4}$, there exist multiple equilibria $(t_L, t_M, t_U) = (t_2, t_2, t_2)$ and (t_2, t_2, t_1). However, given conditions of p_L and p_M implying that θ_L is relatively precise, L's best response in t_2 is to follow θ_L regardless of t_U.[9] Thus, two strategies, $t_U = t_1$ and $t_U = t_2$, are equivalent, i.e., $\pi_i(t_2, t_2, t_2) = \pi_i(t_2, t_2, t_1)$. Therefore, these multiple equilibria are qualitatively identical. What should be noted is that no informed player is willing to disclose his signal, $t_k = t_2$, in these equilibria.

When a game has more than one Nash equilibrium, the risk-dominance criterion by Harsanyi & Selten (1988) is used to select one of them. According to it, one Nash equilibrium risk-dominates another Nash equilibrium if it has a strictly higher Nash product. Here, the Nash product is defined as the product

[8] I assume that player k believes that $\Pr(a_U = h) = \Pr(a_U = l) = \frac{1}{2}$ when U randomizes his action. Given that U randomizes a_U only with a prior belief that $\Pr(w = H) = \Pr(w = L) = \frac{1}{2}$, k has no reason to have a biased belief toward one action. In this sense, $\Pr(a_U = h) = \Pr(a_U = l) = \frac{1}{2}$ is the most reasonable belief.

[9] Recall lemma 3.

of every player's loss incurred when he deviates from the given equilibrium. Now, as to the multiple equilibria derived when $p_L < \frac{3}{4}$ *and* $p^* < p_M$, I consider the risk-dominance criterion.[10]

Corollary 1
When $p_L < \frac{3}{4}$ *and* $p^* < p_M$, $(t_L, t_M, t_U) = (t_1, t_2, t_2)$ *risk-dominates* (t_2, t_2, t_1).

Proof of Corollary 1
In the appendix.

Then, the risk-dominant equilibrium is as follows.

Proposition 2
The risk-dominance criterion yields the following pure strategy Nash equilibrium.
1) If i) $p_L < \frac{3}{4}$ *and* $p_M < p^*$ *or ii)* $p_L > \frac{3}{4}$, $(t_L, t_M, t_U) = (t_2, t_2, \cdot)$.
2) If $p_L < \frac{3}{4}$ *and* $p_M > p^*$, $(t_L, t_M, t_U) = (t_1, t_2, t_2)$.
Here, $p^* = \frac{4p_L - 1}{2} \in (p_L, 1)$.

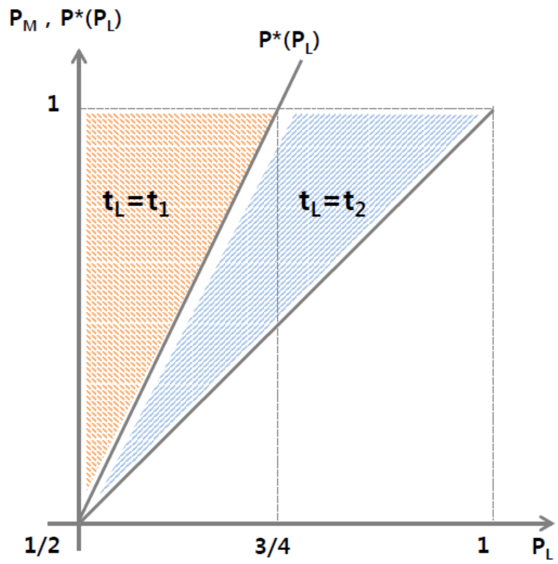
In every risk-dominant equilibrium, $t_M = t_2$.[11] M delays action to prevent θ_M from being revealed to other players. M, who knows that he is the most-informed player, has a relatively strong belief that θ_M is a correct signal. He regards other players' identical actions as strategic substitutes because the reward will be shared if it turns out that $a_M = w$. That is, M's objective is to prevent other players' learning in order to earn the reward alone, which is why he always delays his action.

In the case of L, t_L depends on the relative precision of θ_L compared to θ_M. The key result is that under some condition of p_L and p_M, $t_L = t_1$ in a risk-dominant equilibrium. Considering that there is no cost for delaying action, L is willing to act as the leader. In that case, what would be his gain by acting as the leader? Given that no cost occurs for a delay of action, L expects that $t_M = t_2$, implying that L has no opportunity to infer θ_B and exhibit herding. Then, whether L willingly acts without a delay or not depends on whether he regards U's identical action as a strategic complement or a strategic substitute. Recall that, given that $t_M = t_2$, if $t_L = t_1$ and $t_U = t_2$, U always imitates a_L. Hence, if L thinks that U's identical action causes a positive payoff externality, L's choice should be $t_L = t_1$ in order to induce U's imitation. If not, his choice should be $t_L = t_2$ in order to prevent θ_L from being revealed to U. How the relative precision of θ_L affects this decision can be explained as follows.

The intuition is that the relative precision of θ_L to θ_M determines whether he will hope for the best or prepare for the worst. If θ_L is relatively imprecise compared to θ_M, i.e., $p_L < \frac{3}{4}$ and $p^* < p_M$, L is concerned about the possibility that θ_L is wrong. In that case, L thinks that U's identical action is favorable because, if $a_L = a_U$, the worst case in which L is penalized alone can be avoided. Hence, L willingly takes action in t_1 without a delay. That is, L discloses his private signal voluntarily to induce U's imitation. On the other hand, if θ_L is relatively precise compared to θ_M, i.e., i) $p_L < \frac{3}{4}$ and $p_M < p^*$ or ii) $p_L > \frac{3}{4}$, L gives more weight to the possibility that θ_L is correct. If $a_L = a_U$ when it turns out that $a_L = w$, the reward will be shared. Therefore, L regards U's identical action as a strategic substitute, and so delays his action to prevent U's imitation. In this way, L's confidence in θ_L determines his timing of action, which is no more than a decision of whether or not to disclose θ_L in order to induce imitation.

[10] I do not consider the risk-dominance for the equilibria derived when i) $p_L < \frac{3}{4}$ and $p_M < p^*$ or ii) $p_L > \frac{3}{4}$ because, as mentioned, $t_U = t_1$ and $t_U = t_2$ are equivalent strategies in those cases.

[11] In fact, M delays his action in all risk-dominated equilibria as well.



< Figure 1: L's timing of action in a risk-dominant equilibrium. >

In addition, the risk-dominated equilibrium $(t_L, t_M, t_U) = (t_2, t_2, t_1)$, which is derived when θ_L is relatively imprecise, i.e., $p_L < \frac{3}{4}$ and $p^* < p_M$, is based on L's best response when only U takes action in t_1. Given that $t_L = t_M = t_2$, U should randomize his action regardless of t_U. However, L's best response in t_2 against U's randomized action varies depending on t_U: *i) If $t_U = t_2$, then $a_L = \theta_L$ for all $p_L \in \left(\frac{1}{2}, 1\right)$, ii) if $t_U = t_1$, then L exhibits herding toward a_U when p_L is relatively low.* If $a_U = a_L$, the worst case in which U is penalized alone is avoided. Therefore, given that $(t_L, t_M) = (t_2, t_2)$, the choice $t_U = t_1$, which is likely to induce L's identical action depending on p_L, is a better choice than $t_U = t_2$.

In sum, when θ_L is relatively imprecise to θ_M, there exist multiple equilibria in which the sequential timing of action is derived endogenously. In each equilibrium, either the less- or the least-informed player takes action without a delay in order to be imitated for the sake of avoiding the worst case. Intuitively, the equilibrium $(t_L, t_M, t_U) = (t_2, t_2, t_1)$ in which the player with an informative signal exhibits herding toward the action with no information value is less likely to arise. The risk-dominance criterion sorts it out as a risk-dominated equilibrium and supports the equilibrium $(t_L, t_M, t_U) = (t_1, t_2, t_2)$ in which herding arises toward the action with information value.

3.4 What would happen if M is not considered in the model?

If the most-informed player M is excluded, the player L (the mediocre less-informed player) takes the role of M (the most-informed player). We can show that there exists no pure equilibrium where L's signal is disclosed. Yoon (2009), which considers the two player case with a similar setting, proposes that if delaying action is not costly as in the current model, the equilibrium where the more-informed player discloses his signal does not arise.[12] That is, delaying action must be costly for a revealing equilibrium to exist and it arises only as a mixed strategy equilibrium. This argument can be verified as follows.

[12] The less-informed player delays his action to observe the more-informed player's signal and exhibit herding. The more-informed player also intends to delay his action to prevent the less-informed player's herding. Hence, if a waiting option is available, a delay race arises.

When only L and U are considered, L's best response is as follows. If $t_L = t_1$, $a_L = \theta_L$ always. When $t_L = t_2$ and $t_U = t_1$, if $\theta_L = a_U$, $a_L = \theta_L$. The results of these cases are intuitive. In particular, for the case where $\theta_L \neq a_U$, without loss of generality, let's assume that $\theta_L = l$ and $a_U = h$. Then,

$$\begin{aligned} E\pi_L(a_L = \theta_L) &= \Pr(H|l)(-\gamma) + \Pr(L|l)(\gamma) = \gamma(2p-1) > 0 \\ E\pi_L(a_L \neq \theta_L) &= \Pr(H|l)(\frac{\gamma}{2}) + \Pr(L|l)(-\frac{\gamma}{2}) = -\frac{1}{2}\gamma(2p-1) < 0 \end{aligned}$$

for $p \in \left(\frac{1}{2}, 1\right)$. Hence, $E\pi_L(a_L = \theta_L) > E\pi_L(a_L \neq \theta_L)$, implying that L's best response in this case is to follow his signal. In sum, when $t_L = t_2$ and $t_U = t_1$, regardless of a_U, L's best response as the follower is $a_L = \theta_L$ for all $p_L \in \left(\frac{1}{2}, 1\right)$, implying that a_U does not affect L's choice.

Now, although L's best response is identical whether $t_L = t_1$ or $t_L = t_2$, L's ex-ante expected payoffs in each case are different due to U's best response. If $t_L = t_1$, U imitates a_L. If $t_L = t_2$, U randomizes his choice a_U because a_L is not observable. L's best response when $\theta_L \neq a_U$, which is to always ignore a_U, implies that U's identical action is not beneficial to L. Then, L's equilibrium strategy on the timing of action should be $t_L = t_2$ to prevent U's imitation. It can be shown that, in this case, there exist two pure equilibria $(t_L, t_U) = (t_2, t_1)$ and (t_2, t_2), which are qualitatively identical because U should randomize his action in both cases.

This reasoning explains why the equilibrium where L discloses his signal, $t_L = t_1$, does not arise if only L and U are considered in the model. This also implies that, when three players are considered, L's incentive to induce U's imitation arises because i) he is not the most-informed player and cannot observe the most-informed player's signal and ii) the precision of his signal is much weaker than the precision of the most-informed player's signal.

Therefore, one contribution of this paper is to show that, if more than two players are considered, i) strategic interactions among the less-informed players utilize the payoff externality and ii) a revealing equilibrium where the less-informed player reveals an informative signal exists as a pure equilibrium even when a waiting option is not costly. One common implication of this model and Yoon (2009) is that the most precise information is less likely to be disclosed. Given that the most precise information is not disclosed, if only two players are considered, the option left to another player is to wait and see. On the other hand, if more than two players are considered, the less-informed players are willing to form a coalition and take the same action to minimize their risk, which is their rational strategic choice.

4 Concluding remark

This paper studies the topic of strategic disclosure of information using a setting of an endogenous timing of action game. As action reveals private information and no cost is imposed for a delay of action, the decision to take action without a delay implies willingness to disclose private information. This paper departs from the two player case that has been widely adopted in the literature and finds that considering multiple players may yield a different equilibrium. I consider three players as the simplest case of multiple players. The key result is that, in a risk-dominant equilibrium, only the mediocre less-informed player is willing to disclose his information to induce imitation as long as the precision of his signal is relatively low. Given that he cannot exhibit herding toward an action based on more precise information and he is not confident in his own signal, this is his rational choice. This result suggests that if multiple players are considered, i) asymmetry in the payoff structure and ii) a costly waiting option are not necessary for the existence of a pure equilibrium where information is disclosed to induce imitation. While the simplest case of three players is considered, I believe the main intuition explaining the strategic interactions of the less-informed players can be extended into the case of more players. More sophisticated analysis, based on the preliminary result of this model, awaits future work.

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6 Appendix

6.1 Summary of each player's expected payoffs contingent on t_i

· Player L:

$$\begin{aligned}
\pi_L(t_1,t_1,t_1) &= \pi_L(t_1,t_2,t_1)=\pi_L(t_2,t_2,t_2)=\left(-\frac{1}{12}\right)\gamma\,(4p_M-14p_L+5)\\
\pi_L(t_1,t_1,t_2) &= \left(-\frac{1}{3}\right)\gamma\,(2p_M-4p_L+1)\,,\ \pi_L(t_1,t_2,t_2)=\left(-\frac{1}{6}\right)\gamma\,(p_M-5p_L+2)\\
\pi_L(t_2,t_1,t_1) &= \frac{5}{12}\gamma\,(2p_M-1)\,,\ \pi_L(t_2,t_1,t_2)=\frac{1}{3}\gamma\,(2p_M-1)\\
\pi_L(t_2,t_2,t_1) &= \begin{cases} \left(-\frac{1}{12}\right)\gamma\,(2p_M-1) & \text{if } p_M-7p_L+3>0\\ \left(-\frac{1}{12}\right)\gamma\,(4p_M-14p_L+5) & \text{if } p_M-7p_L+3<0\end{cases}
\end{aligned}$$

· Player M:

$$\begin{aligned}
\pi_M(t_1,t_1,t_1) &= \pi_M(t_1,t_2,t_1)=\pi_M(t_2,t_2,t_2)=\frac{1}{12}\gamma\,(14p_M-4p_L-5)\\
\pi_M(t_1,t_1,t_2) &= \frac{1}{6}\gamma\,(5p_M-p_L-2)\,,\ \pi_M(t_1,t_2,t_2)=\frac{1}{3}\gamma\,(4p_M-2p_L-1)\\
\pi_M(t_2,t_1,t_1) &= \frac{5}{12}\gamma\,(2p_M-1)\,,\ \pi_M(t_2,t_1,t_2)=\frac{1}{3}\gamma\,(2p_M-1)\\
\pi_M(t_2,t_2,t_1) &= \begin{cases} \frac{2}{3}\gamma\,(2p_M-1) & \text{if } p_M-7p_L+3>0\\ \frac{1}{12}\gamma\,(14p_M-4p_L-5) & \text{if } p_M-7p_L+3<0\end{cases}
\end{aligned}$$

· Player U:

$$\begin{aligned}
\pi_U(t_1,t_1,t_1) &= \pi_U(t_1,t_2,t_1)=\pi_U(t_2,t_2,t_2)=\left(-\frac{1}{3}\right)\gamma\,(p_L+p_M-1)\\
\pi_U(t_1,t_1,t_2) &= \frac{1}{6}\gamma\,(5p_M-p_L-2)\,,\ \pi_U(t_1,t_2,t_2)=\left(-\frac{1}{6}\right)\gamma\,(p_M-5p_L+2)\\
\pi_U(t_2,t_1,t_1) &= \left(-\frac{1}{3}\right)\gamma\,(2p_M-1)\,,\ \pi_U(t_2,t_1,t_2)=\frac{1}{3}\gamma\,(2p_M-1)\\
\pi_U(t_2,t_2,t_1) &= \begin{cases} \left(-\frac{1}{12}\right)\gamma\,(2p_M-1) & \text{if } p_M-7p_L+3>0\\ \left(-\frac{1}{3}\right)\gamma\,(p_L+p_M-1) & \text{if } p_M-7p_L+3<0\end{cases}
\end{aligned}$$

6.2 Proof of Corollary 1

The multiple equilibria, $(t_L,t_M,t_U)=(t_1,t_2,t_2)$ and (t_2,t_2,t_1), are derived when $\frac{1}{2}<p_L<\frac{3}{4}$ and $p^*<p_M<1$. For this case,

$$\begin{aligned}
&(\pi_L(t_1,t_2,t_2)-\pi_L(t_2,t_2,t_2))\,(\pi_M(t_1,t_2,t_2)-\pi_M(t_1,t_1,t_2))\,(\pi_U(t_1,t_2,t_2)-\pi_U(t_1,t_2,t_1))\\
>\ &(\pi_L(t_2,t_2,t_1)-\pi_L(t_1,t_2,t_1))\,(\pi_M(t_2,t_2,t_1)-\pi_M(t_2,t_1,t_1))\,(\pi_U(t_2,t_2,t_1)-\pi_U(t_2,t_2,t_2))
\end{aligned}$$

This implies that $(t_L,t_M,t_U)=(t_1,t_2,t_2)$ risk-dominates $(t_L,t_M,t_U)=(t_2,t_2,t_1)$. ■