Sequential Solicitation of Costly Information*

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Abstract

A principal with private information asks agents to acquire costly information and make action recommendations. An agent is then hired to implement his recommendation on the principal's behalf. The optimal mechanism for incentivizing information acquisition and truthful reporting involves approaching agents sequentially without revealing any history and hiring as soon as possible.

An agent's incentive problem features a trade-off between a *majority effect*—reporting truthfully and joining the large group whose recommendations align with the principal's posterior with high probability but, conditional on such alignment, facing a lower chance of being hired from that large group—and a *minority effect*—misreporting and joining the small group whose recommendations align with the principal's posterior with low probability but, conditional on alignment, facing a higher chance of being hired. The minority effect arises only when an agent is pivotal, which occurs with very low probability, so the majority effect typically prevails. However, if the principal is overconfident about the precision of her private information, the minority effect is amplified, and agents gain an additional incentive to second-guess the principal's belief—both channels distort incentives for truthful reporting.

Keywords: Sequential Solicitation, Costly Information Acquisition, Moral Hazard, Adverse Selection, Belief Discrepancy

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1 Introduction

In many decision-making environments, a principal seeks advice from a set of experts and then hires one of them to act on her behalf. These experts can acquire relevant information, but doing so incurs a cost. The principal in this kind of environments faces a fundamental challenge: how to first incentivize experts to exert costly effort and report honestly, and then aggregate information and make an ideal decision. The problem is often more complicated when the principal has her own private information and is overconfident about its accuracy.

Such a problem arises in a wide range of applications. A company with its own internal information might solicit proposals from multiple consulting firms but hires a single team to implement the selected strategy. A patient with private information about her own disease may consult multiple doctors for treatment recommendations but ultimately chooses one of them to perform the procedure. In many of these settings, the principal may overestimate the reliability of her own private signal.

An interesting example of a principal's overconfidence comes from *Book VII of Herodotus*. Xerxes, the King of Persia, wanted to invade Greece. Although all of his advisors suggested him not doing so, Xerxes was highly confident in his private belief, and he consulted his dream several times and each time the man in the dream suggested him invading Greece. Eventually, Xerxes decided to follow the advice from his dreams.

There are also modern examples showing that many corporate leaders are overconfident. In the famous case of acquisition of Autonomy in 2011, Hewlett-Packard (HP), the giant of the computer and printing industry, consulted several consulting firms as well as its internal teams about whether to proceed. Although there were warnings and evidence showing inflated valuations about Autonomy, HP's leaders, especially their CEO at that time, Leo Apotheker, believed in their private information so much that they finally went ahead with the $11 billion deal of acquiring Autonomy. Within a year, the company wrote down $8.8 billion.

We study the above problem by considering a sequential solicitation model under the narrative of an expert-service market. Specifically, a principal who wants to match the state of the world visits multiple agents before hiring one of them, and all agents want to be hired by the principal. When an agent is visited, he first chooses whether to acquire a private signal at a cost, and then he will be asked to make an action recommendation. Eventually, the hired agent is required to execute his recommended action.

This paper models the principal's "overconfidence" by introducing *belief discrepancy* into the above sequential solicitation problem. Specifically, before visiting any agent, the principal privately receives a signal about the state, and the agents and the principal may have disagreement over its precision—belief discrepancy arises when the principal believes in her private signal more than the agents do.

The principal can choose a mechanism to induce agents' effort and truthful reports, and he wants to achieve *informational efficiency* (IE), which is a stronger requirement than optimality; it requires individual rationality (IR) and incentive compatibility (IC), and moreover, the chosen action must be *efficient* with respect to the signals in the sense that it remains weakly better under the principal's updated belief upon stopping regardless of the realizations of signals from unvisited agents.

We first show in Lemma 1 that, given IC and IR as constraints, it is without loss to restrict our attention to the class of mechanisms where agents are not informed of anything about history when they are visited by the principal. This observation on the optimality of pooling information is not only practically intuitive but also greatly simplifies the analysis. Similar observations have also be made in other environments, e.g., Gershkov and Szentes (2009) and Ben-Porath *et al.* (2024).

We consider both cases with and without discrepancy. If there is no belief discrepancy, Proposition 1 shows that a static mechanism can always achieve IE as long as the cost of information acquisition is small. An agent's incentive problem features a trade-off between a *majority effect* and a *minority effect*. Specifically, by reporting truthfully, it is more likely that an agent belongs to the *majority* group of agents whose recommendations are efficient with high probability; however, conditional on recommending the efficient action, the agent faces a lower chance of being hired from that large group. On the other hand, by misreporting, an agent may become one of the *minority* group of agents—with low probability the recommended action is efficient, but conditional on such alignment, being one of the minority brings the agent a higher chance of getting hired. When there is no belief discrepancy, the minority effect arises only when an agent is pivotal, which occurs with very low probability under the agent's belief. A further result is that, given that the static mechanism is IE at some cost of information acquisition, then the sequential mechanism that stops immediately once an efficient action is available must also be IE, and can be IE at a higher cost level. Theorem 1 further shows that such a sequential mechanism can optimally induce the agents' efforts. The intuition is as follows: under such a sequential mechanism, agents tend to believe that the principal will not visit too many agents, and once visited, an agent believes that he is likely visited early and will be hired with high probability as long as he recommends the efficient action.

With belief discrepancy, negative results appear and adverse selection may become a serious issue. We characterize several environments in Section 3.3 under which IE can never be achieved even if the cost of information is arbitrarily small. This happens because a large belief discrepancy not only magnifies the minority effect, but may also provide an additional channel of profitable misreporting. That is, since the agent believes that the principal overestimates the reliability of her own private signal, even under some cases where he is not pivotal, he may still be tempted to strategically misreport his recommendation to align with the perceived overconfidence of the principal (and probably mismatch others' recommendations), thereby increasing his chance of standing out and getting hired. These negative results suggest that the newly introduced belief discrepancy may be an important factor that contributes to agents' dishonest behavior. To resolve such strategic issues, we show in Theorem 2 that the principal can mitigate the influence of belief discrepancy by inviting more agents into this environment; with a large enough number of agents, the strategic issues can be completely resolved since the minority effect will be substantially reduced and the additional channel of profitable misreporting will be narrowed down.

The goal of this paper is to advance the study of information acquisition and solicitation by illuminating the mechanisms that govern communication and delegation. One main takeaway is that the difference in beliefs between the principal and agents can fundamentally alter the dynamics of advice and decision-making. Our analysis explains why overconfident leaders may inadvertently encourage misleading behavior among their advisors, and how broader, more structured consultation processes can promote effective information acquisition and efficient information exchange. Further research is warranted to explore the implications of these insights for organizational design and corporate governance.

1.1 Literature Review

This paper contributes to the understanding of expert-service markets. Pitchik and Schotter (1987) and Wolinsky (1993) analyze the effect of the second opinions and consider situations where the principal cannot observe the type of the service provided. Taylor (1995) and Emons (1997) consider the case where the principal can observe the service provided but is unsure of whether the provided service is needed or not.[1] Glazer and Rubinstein (1998) study the information solicitation problem in two scenarios: a public motive where each expert wants the publicly desirable action to be taken, and a private motive where each expert wants his recommended action to be taken. In our paper, the agents are mostly driven by the private motive; they want their recommended action to be accepted so that they can be hired by the principal. Wolinsky (2002) considers a problem where a decision-maker wants to elicit as much information as possible from a set of experts who are less eager for a high investment than the decision-maker. They show that with limited commitment, the decision-maker can benefit from dividing agents into small groups.

Another strand of literature discusses situations where the experts can exert costly effort to improve diagnostic outcomes (see, for instance, Pesendorfer and Wolinsky (2003), Inderst and Ottaviani (2012), Balafoutas *et al.* (2023), and Baumann and Rasch (2024)), which is also a feature of this paper. In Pesendorfer and Wolinsky (2003), the experts are competing in contracts and each of them can perfectly identify the correct treatment by exerting an effort. The authors conduct an equilibrium analysis and compare the cases with competitive pricing and fixed prices, and show that fixed prices will increase the welfare.

Information solicitation and aggregation is practically relevant in auctions and other selling mechanisms. Crémer *et al.* (2009) and Lauermann and Wolinsky (2017) study information solicitation in auctions, where the seller wants to solicit bidders' values. Lauermann and Wolinsky (2016) study a sequential solicitation problem from a buyer's perspective. Ben-Porath *et al.* (2024) study a sequential solicitation problem of allocating a good where agents are asked to acquire costly evidence.

Information solicitation is also important in voting (see, for instance, Dekel and Piccione (2000), Li *et al.* (2001), Persico (2004), Martinelli (2006), Gershkov and Szentes (2009), and Cai (2009)). Among these papers, Gershkov and Szentes (2009) is most closely related to ours, particularly in its feature of sequential mechanisms and the reasoning for why agents should not be informed of the timeline or others' signals. They study the optimal mechanism that a decision-maker could use to induce agents to acquire information and vote honestly; they show that an optimal ex-post efficient mechanism is sequential and should be based on a decreasing function about the number of visited agents.

This paper also contributes to the literature of mechanism design without transfers,

[1]Some relevant works consider the effect of searching cost / price competitions / scope of insurance on the searching behavior of the consumers and fraud of the experts (see, for instance, Sülzle and Wambach (2005), Mimra *et al.* (2016a), and Mimra *et al.* (2016b)).

where the principal uses exogenous private information together with agents' report to provide incentives.. Kattwinkel and Knoepfle (2023) consider the problem of allocating an indivisible project to the agent, and the principal gets some costless information about the cost of the project while the agent reports a value that is positively correlated with the cost. Pereyra and Silva (2023) consider an assignment problem with the similar intuition. Bloch *et al.* (2023) considers the problem of selecting a suitable candidate from finitely many agents. Our paper is complementary to these papers as we consider a principal who uses her private information to induce the agents' efforts.

Finally, overconfidence is widely recognized as an important feature in real-life decision-making problems. Evidence can be found in the psychology and economics literature, for instance, Weinstein (1980), Svenson (1981), Camerer and Lovallo (1999), Malmendier and Tate (2005), Moore and Healy (2008), and Huffman *et al.* (2022). A wide range of empirical and experimental works study the impact of overconfidence (see, for instance, Daniel *et al.* (1998), Daniel *et al.* (2001), Barber and Odean (2001), Biais *et al.* (2005), Malmendier and Tate (2008), Goel and Thakor (2008), Grubb (2009), Burnside *et al.* (2011), Gervais *et al.* (2011), Ben-David *et al.* (2013), and Zaccaria (2025)). Some theoretical papers have also studied overconfidence from different aspects. Van den Steen (2004) develops a model that helps rationalize why overconfidence are systematically observed among entrepreneurs. Heidhues *et al.* (2018) build a dynamic model of expectation-based learning that leads to persistent overoptimism or misguided learning. Heidhues *et al.* (2025) consider a learning model with overconfident agents that shows how discriminatory beliefs can emerge and persist. A growing literature has been studying the principal-agent model with moral hazard and heterogeneous beliefs, such as Santos-Pinto (2008), de la Rosa (2011), de la Rosa and Lambertsen (2025), Lambertsen (2025), and Dumav *et al.* (2025). As far as we know, this paper is the first one that considers a sequential solicitation problem with the feature of overconfidence.

1.2 Roadmap

The remainder of the paper is organized as follows: we formalize the model and the definitions in Section 2; we analyze the problem and provide the main results in Section 3; the main takeaway and potential extensions are discussed in Section 4; all proofs and additional results are in the Appendix.

2 The Model

The state of the world is $\omega \in \Omega = \{0, 1\}$ with prior $\mu = \Pr[\omega = 0] = \frac{1}{2}$. The action space is $A = \Omega = \{0, 1\}$. The principal wants to match the state and needs the help of an agent to take an action. There are $N \geq 2$ homogeneous agents, indexed by $1, 2, \cdots, N$. When an agent is visited by the principal, there are two phases:

- At phase 1, he decides whether to pay a cost to acquire information; if he pays the cost, he will receive a signal about the state.
- At phase 2, he makes an action recommendation.

We assume that the principal receives the action recommendation without observing whether the agent acquires information or not. The principal can hire at most one agent. There is a fixed payment $r \in (0, \frac{1}{2})$ to hire an agent.[2] We assume that if an agent is hired by the principal, then his recommended action will be taken. The principal can choose not to hire anyone, under which case her payoff is normalized to 0. If agent i with recommended action a_i is hired by the principal, then the principal's payoff is denoted by

$$u(\omega, a_i) = 1 - (a_i - \omega)^2 - r$$

That is, the principal's payoff, if hiring someone, is either 1 (matching) or 0 (not matching) net the fixed payment r. An agent's payoff is simply the payment he gets net any cost of information acquisition, i.e., agent i's payoff is

$$v_i = r \cdot 1\{i \text{ is hired}\} - c \cdot 1\{i \text{ acquires information}\}$$

2.1 Signals and Belief Discrepancy

Before visiting any agent, the principal receives a private signal $\mathcal{S}_P \in \{s_0, s_1\}$ about the state of the world. Belief discrepancy exists if the agents and the principal have different opinions about the precision of that signal.

It is common knowledge that the agents believe that the precision of the principal's private signal is $q \in (\frac{1}{2}, 1)$, that is, $\mathcal{S}_P$ is drawn from distribution $\pi_P(\cdot|\omega)$ with $\pi_P(s_0|\omega = 0) = \pi_P(s_1|\omega = 1) = q$. It is also common knowledge that the principal believes that the precision of her private signal is $q' \in [q, 1]$, that is, $\mathcal{S}_P$ comes from distribution $\pi'_P(\cdot|\omega)$ with

[2] We assume r to be relatively small so that it won't make the principal quit without hiring. In Section 2.4, we will talk about why we need exactly $r < \frac{1}{2}$.

$\pi'_P(s_0|\omega=0) = \pi'_P(s_1|\omega=1) = q'$.

π_P	s_0	s_1
$\omega=0$	q	$1-q$
$\omega=1$	$1-q$	q

π'_P	s_0	s_1
$\omega=0$	q'	$1-q'$
$\omega=1$	$1-q'$	q'

There is no belief discrepancy if $q = q'$, and we say that the principal is **overconfident from the agent's perspective** if $q < q'$.[3]

Before making any recommendation, agent i can pay a cost $c > 0$ to get a private signal $\mathcal{S}_i \in \{s_0, s_1\}$ with precision $p \in (\frac{1}{2}, 1)$ about the state. We assume that the agent's signals are conditionally independent, each of which comes from distribution $\pi(\cdot|\omega)$ with $\pi(s_0|\omega=0) = \pi(s_1|\omega=1) = p$.

For ease of notations, define $a_{s_0} = 0$ and $a_{s_1} = 1$. To make the problem interesting, we assume that q' is not too large; specifically, with N opposite signals from the agents, the principal's private signal will be overturned, i.e.,

$$\frac{q'(1-p)^N}{q'(1-p)^N + (1-q')p^N} < \frac{1}{2} \quad \text{or} \quad q' < \frac{p^N}{p^N + (1-p)^N}$$

2.2 Space of Mechanisms

Define (p, q, q', N) as a problem if the above assumption $q' < \frac{p^N}{p^N+(1-p)^N}$ is satisfied. Given a problem, the principal is allowed to flexibly choose her mechanism to induce information and make the hiring decision within the mechanism space $\mathcal{G}$ as defined below. In brief, a mechanism should specify the next move of the principal given any history.

History

Define the initial history as $H_0 \in \mathcal{H}_0 = \Big\{\{s_0\}, \{s_1\}\Big\}$, the only component of which is the principal's private signal. A history of length $T \in \{1, \cdots, N\}$ is some $H_T = (H_0, h_1, \cdots, h_T)$ such that $\sum_{i=1}^T |h_t| \leq N$ where h_t is the set of action recommendations received in period $t \in \{1, \cdots, T\}$. Let $\mathcal{H}_T$ denote the set of all possible histories of length T, and $\mathcal{H} = \cup_{T=0}^N \mathcal{H}_T$ denote the set of all possible histories.

[3] We are not making any assumption about who has the correct belief.

Mechanism

A mechanism $G \in \mathcal{G}$ will take at most $N_G \leq N$ periods.[4] Given mechanism $G \in \mathcal{G}$, for any $T \in \{0, 1, \cdots, N_G - 1\}$, let $\mathcal{H}_T^G \subset \mathcal{H}_T$ denote the set of possible histories of length T. We use $\mathcal{H}^G = \cup_{T=0}^{N_G-1} \mathcal{H}_T^G \subset \mathcal{H}$ to denote the set of possible histories given mechanism G. Specifically, under mechanism G, at the beginning of each period $T = 1, 2, \cdots, N_G - 1$, given the current history H_{T-1}, the principal decides whether to continue visiting more agents at period T or not.

- If continue, the principal chooses the number of agents $N_T \geq 1$ to be visited at period T. Then N_T of the remaining unvisited agents are selected uniformly at random to be visited by the principal. The principal also chooses $\mathcal{H}' \subset \mathcal{H}^G$ such that $H_{T-1} \in \mathcal{H}'$, and the agents visited in this period learns that the current history belongs to $\mathcal{H}'$.[5] After receiving an action recommendation from each of the N_T agents, history H_T is recorded, and the principal moves on to period $T + 1$.

- If stop, the principal chooses who to hire among all visited agents.

Forms of mechanisms

A **static mechanism** is a mechanism under which the principal asks for action recommendations from all or a subset of agents simultaneously at $T = 1$ and then makes the hiring decision at the beginning of $T = 2$. Let $\mathcal{G}_0$ denote the class of static mechanisms.

A **sequential mechanism** is a mechanism under which the principal visits one agent at a time before she stops. Let $\mathcal{G}_1$ denote the class of sequential mechanisms. Note that any mechanism can be modified to become a sequential mechanism that is essentially equivalent to the original mechanism. Therefore, $\mathcal{G}_0 \subset \mathcal{G}_1 = \mathcal{G}$.

Stopping rule and hiring rule

Note that a mechanism $G \in \mathcal{G}$ specifies a stopping rule and a hiring rule. Specifically, a stopping rule specifies the probability of stopping at the beginning of each period T given

[4]There must be $N_G \leq N$ because we assume that an agent will never be visited more than once.

[5]We assume that the agents themselves cannot observe any information about the history; however, if the principal shares $\mathcal{H}' \subset \mathcal{H}^G$ with the agent, then he may update his belief about the history based on $\mathcal{H}'$ and mechanism G.

any history H_{T-1}; a hiring rule specifies the probability of hiring each visited agent given history H_{T-1} when the principal stops visiting at the beginning of period T.

2.3 Principal's Belief Updating

Suppose that at the end of period $T-1$, n out of N agents have been visited, and every visited agent acquired information and reported it truthfully, then the principal's current belief over state $\omega \in \Omega$ is simply determined by the following factors: her private signal $\mathcal{S}_P$, the number of agents n_ω who recommend action $a = \omega$, the number of agents $n - n_\omega$ who recommend the other action.[6]

Let $B_\omega(\mathcal{S}_P, n_\omega, n - n_\omega)$ denote the principal's updated belief over state ω. Then at the beginning of period T, denote $n_1 = n - n_0$, then the principal's updated belief over state $\omega = 0$ is

$$B_0(\mathcal{S}_P, n_0, n_1) = \begin{cases} \frac{q' p^{n_0 - n_1}}{q' p^{n_0-n_1} + (1-q')(1-p)^{n_0-n_1}} & \text{if } \mathcal{S}_P = s_0 \\ \frac{(1-q')(1-p)^{n_1-n_0}}{(1-q')(1-p)^{n_1-n_0} + q' p^{n_1-n_0}} & \text{if } \mathcal{S}_P = s_1 \end{cases}$$

In the case where all agents acquire information and make truthful reports, from the principal's perspective, it never hurts to ask for more action recommendations from the agents. Nevertheless, by visiting more agents, the number of unvisited agents will decrease, meaning that at some point of the visiting process, the principal's updated belief over one action will be so strong that it won't be overturned by the unvisited agents even if all unvisited agents recommend the other action. Such an action is defined as an efficient action.

Definition 1. *Let agent i who recommends action $a_i \in \{0, 1\}$ be one of the agents who are visited before period $T+1$. We say that action a_i is* ***efficient*** *from the perspective of the principal at the end of period T if*

$$B_{a_i}(\mathcal{S}_P, n_{a_i}, N - n_{a_i}) \geq \frac{1}{2}$$

where n_{a_i} is the number of agents who recommend action a_i before period T, and then $B_{a_i}(\mathcal{S}_P, n_{a_i}, N - n_{a_i})$ is the principal's posterior belief over state $\omega = a_i$ when she finishes

[6]Some abuse of terminology: when we say an agent reports the information truthfully or making a truthful recommendation, we are saying that the agent is recommending the action that aligns with the private signal he receives. Similarly, misreporting means an agent is recommending the action that is opposite to the signal he receives.

visiting all agents and finds that all agents visited at and after period T recommend action $a \neq a_i$ by assuming every agent acquires the information and reports it truthfully.

In other words, an action a is found to be efficient by the principal at some point if given the current number of agents who recommend this action, even if all other agents acquire information and truthfully recommend the opposite action, the principal still believes that action a is (weakly) more likely to be the correct action.

2.4 Informational Efficiency

The principal in this paper wants to achieve informational efficiency, which is definied as follows:

Definition 2. *Given a problem (p, q, q', N) and $c > 0$, a mechanism is* ***informationally efficient (IE)*** *if*

(i) it induces an equilibrium in which every visited agent acquires information (IR) and reports it truthfully (IC);

(ii) if an agent who recommends action a is hired in period T, then a is efficient at the end of period $T - 1$;

(iii) some agent is hired.

Since informational efficiency requires that the selected action should be efficient from the principal's perspective, an IE mechanism, if exists, must be optimal.

One may argue that informational efficiency may be too strong as a requirement for the mechanism from a technical perspective. We acknowledge that IE may not be perfect, but we believe that it is a very practical objective from the perspective of the principal since visiting is costless. Moreover, setting informational efficiency as the target makes our results cleaner. Specifically, given the features of costly information acquisition and different payoff structures between agents and the principal, if we want to characterize optimality in the full domain, then we may have to introduce randomization into the agents' decisions on information acquisition, which is something we want to avoid. A more reasonable extension than this is to study constrained optimality in the sense that the principal still wants to make sure that every agent exerts the costly effort and truthfully reports the signal if he is asked to do so, but it is no longer required that an efficient action should be chosen – we leave this extension for future work.

Now, we briefly discuss why the principal will never choose a mechanism that specifies a positive probability of quitting without hiring given $r < \frac{1}{2}$. If an IE mechanism exists, with a payment $r < \frac{1}{2}$, the principal will always get a positive expected payoff by hiring someone who recommends an efficient action. If an IE mechanism doesn't exist, the principal can still guarantee a strictly positive expected payoff by doing the following: inform the first visited agent about her private signal and ask him to recommend the corresponding action without acquiring information, and then hire him. In brief, by assuming $r < \frac{1}{2}$, the fixed payment will not really enter the principal's problem so that it won't affect our result.

One can also see that if the cost of information acquisition is too large, then none of agents will have incentives to acquire information, which leads to the nonexistence of IE mechanisms. Therefore, in the rest of the paper, our first target is to identify the scope of cost c under which moral hazard could be resolved by a mechanism. On top of that, given a small enough cost c such that moral hazard is not an issue, it is unclear whether adverse selection will be an issue, and we want to study the role of belief discrepancy there.

3 Results

3.1 Analysis

3.1.1 Threshold k

Given any problem (p, q, q', N), define $k = k^*(p, q', N) \in \{1, 2, \cdots, [\frac{N}{2}] + 1\}$ as the smallest number such that with k agents truthfully recommending action $a_{\mathcal{S}_P}$, the principal believes that $a_{\mathcal{S}_P}$ is efficient, i.e., k satisfies the following two inequalities:

$$\frac{p^{k-1}(1-p)^{N-k+1}q'}{p^{k-1}(1-p)^{N-k+1}q' + (1-p)^{k-1}p^{N-k+1}(1-q')} < \frac{1}{2}$$

$$\frac{p^{k}(1-p)^{N-k}q'}{p^{k}(1-p)^{N-k}q' + (1-p)^{k}p^{N-k}(1-q')} \geq \frac{1}{2}$$

which can also be rewritten as

$$q'(1-p)^{N-2k+2} < (1-q')p^{N-2k+2}$$

$$q'(1-p)^{N-2k} \geq (1-q')p^{N-2k}$$

Note that such k must exist since the problem requires $q' < \frac{p^N}{p^N+(1-p)^N}$, and k is a function of p, q', and N. Fix p and q', as N increases, k weakly increases. One can observe that

$$\lim_{N\to\infty} \frac{k}{N} = \frac{1}{2}$$

In most of the cases, there exists a unique efficient action. However, if the second inequality happens to be binding, it could be the case that both actions are efficient. For example, when $p = q'$ and $N = 2k+1$, we must have $q'(1-p)^{N-2k} = (1-q')p^{N-2k}$; if k agents recommend $a_{\mathcal{S}_P}$ while the other $N-k$ agents recommend the other action, then both actions are efficient.

To simplify our analysis and descriptions of results, we do not consider any problem with possibly two efficient actions. One should note that such a refinement of problems will not affect the generality of our results due to a simple construction—each time we encounter a problem with possibly two efficient actions, we can remove one agent out of the problem and instead consider the problem with the remaining agents. That is, if $q'(1-p)^{N-2k} = (1-q')p^{N-2k}$, then we turn to consider the problem with $N-1$ agents. Indeed, given $q'(1-p)^{N-2k} = (1-q')p^{N-2k}$, if there exists no IE mechanism with $N-1$ agents, then there exists no IE mechanism with N agents, either. This point is explained by Proposition 4 together with Lemma 4 in Appendix B. In the remaining of the paper, we assume that there is a unique IE action, i.e.,

$$q'(1-p)^{N-2k} > (1-q')p^{N-2k}$$

As a result, if k agents recommend $a_{\mathcal{S}_P}$, then action $a_{\mathcal{S}_P}$ is the only efficient action; if $N-k+1$ agents recommend the other action, then that action becomes the unique efficient action.

3.1.2 Canonical Mechanisms

Let $\mathcal{G}^* \subset \mathcal{G}$ denote the class of mechanisms where

(i) no information is disclosed to any agent;

(ii) someone is hired by the principal;

(iii) the hired agent recommends an efficient action.

Note that any mechanism in $\mathcal{G}^*$ that is IR and IC must be IE given the definition of IE. With the following Lemma 1, given that informational efficiency is our target, it is without loss to focus on the class $\mathcal{G}^*$.

Lemma 1. *Given any problem and $c > 0$, if there exists $G \in \mathcal{G}$ such that G is IC and IR, then there exists $G^* \in \mathcal{G}^*$ such that G^* is IC and IR, and hence is informationally efficient.*

Proof of Lemma 1. See Appendix A.1.

We first address why the principal should not reveal any information about the history. In fact, under any mechanism, each agent is facing an information set upon being visited. If it is a mechanism from $\mathcal{G}^*$, then the information sets are exactly the same across all agents; however, if otherwise, there will be at least two different information sets that could possibly appear. To make a mechanism IR and IC, multiple pairs of IR and IC constraints should hold at the same time under mechanism $G \notin \mathcal{G}^*$. If G and G^* have the same stopping rule and hiring rule, we show in Appendix A.1 that the IR/IC constraint for G^* is a convex combination of the multiple IR/IC constraints for G. That is, as long as G is IR and IC, then G^* must also be IR and IC.

More intuitively, in the extreme case where every agent is informed and only informed of their order of being visited, there are N different information sets, and hence N different pairs of IC/IR constraints. To make such a mechanism IC and IR, all constraints need to be satisfied. With the same stopping rule and hiring rule, the mechanism in $\mathcal{G}^*$ has a single pair of IC/IR constraints, which equals to the average of the N pairs of constraints and should be easier to satisfy. More specifically, assume that the principal is using a sequential mechanism with the following stopping and hiring rules: stop visiting immediately once an efficient action is clear, and agents who recommend the efficient action are hired with equal probabilities. Then, the agent who learns that he is the last one to be visited will be extremely hard to incentivize, since conditional on the fact that he is the last one being visited, he knows that the principal hasn't found out the efficient action yet, and whatever he recommends will become the efficient action—the agent will then have no incentive to acquire information.

Lemma 1 implies that to study informational efficiency, it is without loss to study IC and IR mechanisms in G^*. The following Lemma 2 is very useful in the proofs of some later results. It shows that, whether a mechanism is IE or not doesn't really rely on a specific hiring rule; fix the form of the mechanism and the stopping rule, we may adjust the hiring rule as we want within $\mathcal{G}^*$, and it won't change any IR or IC constraints. In other words, any two sequential mechanisms in $\mathcal{G}^*$ with the same stopping rule are essentially equivalent to each other.

Lemma 2. *Given any problem and $c > 0$, if $G^1 \in \mathcal{G}^* \cap \mathcal{G}_1$ and $G^2 \in \mathcal{G}^* \cap \mathcal{G}_1$ are sequential mechanisms with the same stopping rule, then G^1 is informationally efficient if and only if G^2 is informationally efficient.*

Proof of Lemma 2. See Appendix A.2.

Given that G^1 and G^2 have the same stopping rule, then upon being visited by the principal, an agent is facing the same information set under these two mechanisms. Conditional on that there are altogether n people who are visited under both mechanisms, the agent believes that he will be hired with probability $\frac{1}{n}$ anyway, regardless of the hiring rule. Moreover, when visited, an agent's belief on "altogether n agents being visited" will be the same under the two mechanisms. Therefore, any visited agent believes that he will be hired with the same probability under these two mechanisms, meaning that the two mechanisms are essentially equivalent.

3.1.3 Agent's Best Response

Under any mechanism $G \in \mathcal{G}^*$, when an agent is visited, he faces an information set I_G. At information set I_G, given that everyone else who has been visited acquired the information and reported it truthfully to the principal, the agent decides whether to acquire information. Let V_G^α denote the probability of agent i being hired if he chooses to acquire information and report it truthfully, and V_G^β denote the probability of being hired if misreporting after acquiring the information. Then if he chooses not to acquire information and makes a random recommendation, the probability of being hired is given by

$$V_G^0 = \frac{V_G^\alpha + V_G^\beta}{2}$$

We can now write out the IR and IC constraint at information set I_G:

$$\text{IR:} \quad r \cdot \max\left\{V_G^\alpha, V_G^\beta\right\} - c \geq r \cdot V_G^0$$
$$\text{IC:} \quad r \cdot V_G^\alpha - c \geq r \cdot V_G^\beta - c$$

The above constraints imply

$$V_G^\alpha - V_G^\beta \geq \frac{2c}{r} > 0$$

Since any IR and IC mechanism in $\mathcal{G}^*$ must be IE, we conclude that $G \in \mathcal{G}^*$ is IE if and only if the above condition is satisfied.

3.2 Without Belief Discrepancy: $q' = q$

We first assume $q' = q$. Then there is no belief discrepancy. It turns out that under such a case, the following static mechanism G_0 is IE as long as the cost of information acquisition is relatively small.

Define $G_0 \in \mathcal{G}^* \cap \mathcal{G}_0$ as the static mechanism under which
(i) the principal asks for action recommendations from all agents simultaneously;
(ii) agents who recommend the efficient action are hired with equal probabilities.

Proposition 1. *Given any problem without belief discrepancy ($q = q'$), there exists $c_0 > 0$ such that G_0 is informationally efficient if and only if $c \in (0, c_0]$.*

Proof of Proposition 1. See Appendix A.3.

To make G_0 IE, we need to make sure that every agent is induced to acquire information and report it truthfully in equilibrium. Simply take $c_0 = \frac{r}{2}(V^\alpha_{G_0} - V^\beta_{G_0})$. We only need to show that $V^\alpha_{G_0} - V^\beta_{G_0} > 0$.

Intuitively, to make an agent himself hired by the principal, an agent has to become one of the agents who recommend the efficient action. Given that everyone else makes a truthful report, reporting it truthfully brings the agent a high probability of recommending the efficient action. However, in order to match the efficient action, the agent may not have to report the signal truthfully. Specifically, if an agent finds himself "pivotal", he may choose to misreport so that he can maximize his probability of being hired. To see this, let's consider the following example with $N = 5$ agents. Assume that the principal's private signal has a relatively high precision, and $k = 2$, so she needs $N - k + 1 = 4$ opposite recommendations to overturn her private signal. Consider the scenario where the principal receives a signal s_1, and one of the other agents recommends action 0 while three others recommend action 1. The agent now becomes pivotal in the sense that his recommendation will determine which action is efficient. Under such a case, he will always choose the action that is recommended by fewer agents regardless of what signal he receives, and such a force, which we call it a *minority effect*, provides some incentives for the agent to misreport. Indeed, conditional on this scenario, it's better for him to recommend action

0 even though he receives signal s_1, as by recommending action 0 he will be hired with probability 0.5, and otherwise he will be hired with probability 0.25.

On the other hand, there is also a *majority effect*, as conditional on the fact that an agent is not pivotal, the efficient action is already clear to the principal even without his recommendation, and hence it is always better for him to tell the truth so that he can match the efficient action with high probability. In other words, there is always a trade-off between matching the majority's recommendation and trying to be one of the minority. The former leads to high probability of recommending an efficient action, but there may be too many people recommending the same action, which further leads to low probability of being hired; the latter sacrifices some probability of recommending an efficient action, but if it happens that the agent is pivotal, then the minority effect brings him higher conditional probability of being hired.

It turns out that, when there is no belief discrepancy, the minority effect is quite weak—the incentives to misreport generated by the minority effect can be fully offset by those from the majority effect.

Note that a static mechanism can also be written in the form of a sequential mechanism where the principal never stops until all agents are visited. A natural question is, whether there exists a stopping rule that can do strictly better than G_0, i.e., achieve informational efficiency even with a strictly larger cost of information acquisition. Our next result shows that, the following sequential mechanism G_1 can optimally overcome moral hazard. Specifically, it is IE even when there is a relatively large cost of information acquisition; if the cost is so large that G_1 is not IE, then there exists no IE mechanism.

Define $G_1 \in \mathcal{G}^* \cap \mathcal{G}_1$ as the sequential mechanism under which

(i) the principal immediately stops visiting once an efficient action is available;

(ii) agents who recommend the efficient action are hired with equal probabilities.

Theorem 1. *Given any problem without belief discrepancy ($q = q'$), there exists $c_1 > c_0$ such that*

(1) G_1 is informationally efficient if and only if $c \in (0, c_1]$;

(2) there exists no informationally efficient mechanism if $c > c_1$.

Proof of Theorem 1. See Appendix A.4.

The main takeaway from Theorem 1 is that, the sequential mechanism G_1 can optimally overcome moral hazard. To see why it is the case, one should note that in the expectation of a visited agent, fewest number of agents would be visited under G_1, leading to a relatively high probability of being hired if he can match the efficient action, which generates a large incentive to acquire information.

Besides, we also want to understand why adverse selection is not an issue. Based on Proposition 1, we only need to show $V^{\alpha}_{G_1} - V^{\beta}_{G_1} > V^{\alpha}_{G_0} - V^{\beta}_{G_0}$. This requires a connection be built between G_0 and G_1. Note that by Lemma 2, G_0 is essentially equivalent to the sequential mechanism G_0' with the following hiring rule: let T be the period at the end of which the principal learns the efficient action for the first time, and the agents who recommend the efficient action before or at period T are hired with equal probabilities. Meanwhile, we keep its original stopping rule of never stopping until all agents are visited. Now, with the exactly same hiring rule, we can compare G_0 and G_1 easily by comparing G_0' and G_1. Then, when an agent is visited under mechanism G_0', there are two possible cases: (i) the efficient action is not clear yet, under which case his belief is exactly the same as being visited under G_1; (ii) the efficient action is already clear, under which case he will never be hired. This implies that $V^{\alpha}_{G_0} - V^{\beta}_{G_0}$ is a convex combination of $V^{\alpha}_{G_1} - V^{\beta}_{G_1}$ and 0.

3.3 With Belief Discrepancy: $q' > q$

In this section, we consider cases with belief discrepancy, i.e., $q' > q$. The following proposition characterizes all problems with $N = 3$ for which there exists no IE mechanism even if the cost of information acquisition is arbitrarily small.

Proposition 2. *Suppose that $N = 3$. There exists no informationally efficient mechanism for any $c > 0$ if and only if $q \leq \frac{1+p}{3} < \frac{1+q'}{3}$.*

Proof of Proposition 2. See Appendix A.5.

To understand how forces change as belief discrepancy occurs and increases, we look at the following Example 1 and consider only the static mechanism G_0 for simplicity. The sequential mechanism G_1 can of course better overcome moral hazard, but is unable to fix adverse selection if the static mechanism G_0 also leads to adverse selection. This point is explained by Lemma 4 in Appendix B.

Example 1. *Problem (p, q, q', N): $p = 0.6$, $q' = 0.7$, $N = 3$. Then $k = 1$. Assuming the other two agents acquire information and make truthful reports, we consider the best response of an agent.*

Here are the only two situations conditional on which the agent finds himself more likely to be hired if misreporting:

1. *The agent receives s_0, the principal receives s_1, and the other two agents receive s_0;*
2. *The agent receives s_1, the principal receives s_0, and the other two agents receive s_1.*

Under both situations, the agent is pivotal, and can benefit from misreporting due to the minority effect. Conditional on all other situations, the majority effect provides incentives for the agent to acquire information and report it truthfully.

Now, consider a decrease of belief q from 0.7. At $q = 0.7$, there is no belief discrepancy, and as we show in Proposition 1, the minority effect is too weak compared to the majority effect. However, as q decreases, the probabilities that the two situations with a minority effect happen increase. Although the benefit of misreporting doesn't change conditional on either situation, the incentive to misreport increases in general.

In brief, belief discrepancy amplifies the minority effect, and as belief discrepancy increases, if at some point, the minority effect beats the majority effect, then the agent will choose to misreport. The following result shows that, for problems with $N \geq 4$, negative results also widely exist.

Proposition 3. *For any $N \geq 4$ and $p \in (\frac{1}{2}, 1)$, there exist $q \in (\frac{1}{2}, p)$ and $q' \in \left(p, \frac{p^N}{p^N+(1-p)^N}\right)$ such that for problem (p, q, q', N), there exists no informationally efficient mechanism for any $c > 0$.*

Proof of Proposition 3. See Appendix A.6.

The basic intuition is still to make belief discrepancy large enough and the agents' signal precision p lies between the two subjective signal precisions q and q'. One can see that belief discrepancy still magnifies the minority effect by generating a higher probability that the agent finds himself pivotal, and hence he would misreport to get a hire chance of getting hired. Moreover, when $N \geq 4$, belief discrepancy actually creates another channel of profitable misreporting even when the agent is not pivotal. We use the following Example 2 to explain this point.

Example 2. *Problem (p, q, q', N): $p = 0.7$, $q' = 0.9$, $N = 4$. Then $k = 1$. Assuming the other three agents acquire information and make truthful reports, we consider the best response of an agent.*

Suppose that the agent knows that he is at one of the following two situations:

S1. The principal receives s_1, one of the other agents receives s_1 while the other two agents receive s_0;

S2. The principal receives s_0, one of the other agents receives s_0 while the other two agents receive s_1.

Under either situation, the agent is not pivotal: under situation 1, action 1 is efficient from the perspective of the principal, while under situation 2, action 0 is efficient.

If $q = q' = 0.9$, there is no belief discrepancy. To make himself hired, the best response conditional on situations 1 and 2 is to report truthfully—when receiving signal s_0, situation 2 happens with a higher probability, under which case he should recommend action 0 to get hired; when receiving s_1, situation 1 happens with a higher probability, under which case he should recommend action 1.

However, if $q < q'$, there is belief discrepancy. After receiving a signal, he computes the conditional probabilities of situations 1 and situation 2 using his belief q instead of q'. Specifically, when receiving s_0, situation 1 happens with probability

$$\begin{aligned} P\big(S1\big|S1\&S2, s_0\big) &= \frac{qp(1-p)^3 + (1-q)(1-p)p^3}{qp(1-p)^3 + (1-q)(1-p)p^3 + qp^2(1-p)^2 + (1-q)(1-p)^2p^2} \\ &= \frac{0.49 - 0.4q}{0.7 - 0.4q} \end{aligned}$$

Note that, if $q < 0.7 = p$, then $P\big(S1\big|S1\&S2, s_0\big) > 0.5$, meaning that conditional on receiving s_0 and situations 1 and 2, it is more likely that the agent is at situation 1, under which he will need to recommend action 1 to get himself hired. Symmetrically, conditional on receiving s_1 and situations 1 and 2, it is more likely that the agent is at situation 2, where he wants to recommend action 0.

To briefly conclude, even when the agent is conditional on some situations where he is not pivotal, if there is a large enough belief discrepancy, he may still want to misreport. This is an additional channel of profitable misreporting created by belief discrepancy, which only takes place when $N \geq 4$ and plays as an incentive to misreport in addition to the minority effect. Such a force comes from the fact that the agent has a different opinion with the principal about which action is efficient due to the belief discrepancy.

Therefore, with a strong enough minority effect together with the above nonnegligible channel, a strategic agent may have incentive to guess and match the principal's private signal instead of recommending the action that is more likely to be efficient from his own perspective. In Appendix B, we characterize the set of problems for which there is no IE mechanism for any $c > 0$ in Theorem 3. We also provide a method in Proposition 6 to identify more problems given that we already have one such problem: when N is fixed, the nonexistence of IE mechanisms remains as q decreases or q' increases.

Given these negative results, the ultimate question would be the following: what should the principal do if she wants to get an ideal outcome when IE mechanism is not available due to adverse selection? There are two main directions to consider.

The first direction to consider may simply be giving up IE. As we argued in Section 2.4, a reasonable approach to still consider the set of mechanisms where agents acquire information and report it truthfully. This is not the main focus of this paper, but as a corollary of Proposition 5 in Appendix B, we know that any problem with $N = 2$ will not lead to adverse selection, and hence we propose the following mechanism:

• If q' is relatively large such that the principal's private signal cannot be overturned by two opposite signals from agents, then she simply visits an agent and shares her private signal with him, and then hire him with probability 1 as long as his recommendation aligns with her private signal.

• If otherwise, then the principal chooses two of the agents and let all agents know that these two agents would be the only two agents to be visited. The principal then applies mechanism G_1 as if she is at a problem with only these two agents.

We now focus on the other direction where IE is maintained as the objective of the principal. It turns out that fixing precisions p, q, and q', if the principal can invite a large enough number of agents to come to the problem, then adverse selection may be resolved.

Theorem 2. *Given any p, q, q', there exists $N^*(p, q, q') \geq 3$ such that for any problem (p, q, q', N) with $N > N^*(p, q, q')$, there exist $c_1 > c_0 > 0$ such that*

(1) G_0 is informationally efficient if and only if $c \in (0, c_0]$;

(2) G_1 is informationally efficient if and only if $c \in (0, c_1]$;

(3) there exists no informationally efficient mechanism if $c > c_1$.

Proof of Theorem 2. See Appendix A.7.

Note that k/N increases and converges to $1/2$ as N increases. That is, by involving a large enough number of agents into the problem, the principal may need nearly a half of the agents to confirm her private signal before she believes that her private signal leads to an efficient action. This means that, when an agent finds herself pivotal and wants to stay in the minority group, the number of agents in the minority group is close to the number of agents in the majority group. This largely reduces the minority effect.

We should also check the additional channel of profitable misreporting we mentioned in Example 2. One can show that such a channel has to take place in the following way: $N = 2k + \ell + 1$, and $m \in \{0, 1, \cdots, [\frac{\ell-1}{2}]\}$, and the agent believes that he is at one of the following two situations:

S1. The principal receives s_1, $k + m$ of the other agents receives s_1 while the other $k + \ell - m$ agents receive s_0;

S2. The principal receives s_0, $k + m$ of the other agents receives s_0 while the other $k + \ell - m$ agents receive s_1.

Still, with a large belief discrepancy, the agent may want to misreport if he is conditional on situations 1 and 2 and receiving s_0 because when he receives s_0, it's more likely he is at situation S_1 where he wants to recommend action 1. Such an incentive to misreport comes from the conditional probability difference of S1 and S2. Note that ℓ is constant as N increases. When N is large enough, ℓ and m are extremely small compared to k and N, which means that, when N is large enough, such difference will be very small.

Given that the minority effect is substantially reduced and the additional channel of profitable misreporting is also narrowed down, it is not surprising that adverse selection can be completely resolved by choosing a large enough N.

4 Concluding Remarks

This paper studies a problem of inducing a set of agents to acquire information and make honest recommendations. The principal holds a private signal, the precision of which may be overrated by herself from the agents' perspective. Such a feature of belief discrepancy captures the fact that many CEOs and policymakers may be overconfident in the views of their advisors.

We first show that it is without loss to consider the sequential mechanisms where each agent is not informed anything about the history. Given that the principal's target is to achieve information efficiency, with a small enough cost of information, if there is no belief discrepancy, although there is a trade-off between the minority and the majority effect, it turns out an IE mechanism is always achievable by applying either a static mechanism or a sequential mechanism that stops immediately when an efficient action is clear—the latter is also shown to be the best mechanism to overcome moral hazard.

With belief discrepancy, the agent's incentive to misreport is strengthened due to a stronger minority effect and a potential disagreement on which action is efficient. As a result, the agent may try to guess and match the principal's private signal rather than make a truthful report. Our results indicate that belief discrepancy plays a very important role in adverse selection issues in our model. To reduce the minority effect and narrow down the additional channel of profitable misreporting, the principal could try to involve more agents into the problem, which may eventually resolve adverse selection.

There are two reasonable extensions of our model. One is to allow some flexibility in the principal's hiring decisions. Specifically, in the current model, the hired agent has to perform the action that is recommended by himself. If, instead, the principal can ask the hired agent to perform any action, or the principal can even hire someone who is not visited, then it would be interesting to consider whether adverse selection could be avoided when there is belief discrepancy. The other extension is to consider a weaker target of the principal. As we explained before, it would be interesting to study the case where choosing an efficient action is no longer a requirement when an IE mechanism is not achievable. We leave these extensions for future work.

Appendix

A Proofs.

A.1 Proof of Lemma 1.

Given $c > 0$, take any mechanism $G \in \mathcal{G}$ such that G is IC and IR, and write it as a sequential mechanism. Define $G^* \in \mathcal{G}^*$ as the sequential mechanism where agents are not informed of anything about history, and G^* and G have the same stopping rule and hiring rule. This is well-defined since both G^* and G are sequential mechanisms. Specifically, having the stopping and hiring rule will generate the same set of possible histories; on the other hand, given that the set of possible histories is the same at these two mechanisms, we can define the stopping and hiring rules on the same domain. Let $\mathcal{H}$ denote the set of possible histories for both mechanisms.

We are done if $G^* = G$. If not, we will show that G^* must be IC and IR given that G is IC and IR.

Under G^*, upon being visited, each agent encounters the same information set I^* at which he believes that he is at history $H \in \mathcal{H}$ with probability $R(H|I^*)$.

On the other hand, under G, there exists at least one agent who learns that he is at a history that belongs to $\mathcal{H}' \subsetneq \mathcal{H}$. Denote $I(G) = \{I_1, \cdots, I_M\}$ as the set of possible information sets that could appear under mechanism G. Given G as well as the information about history learned from the principal, an agent will encounter an information set $I_m \in I(G)$ with probability $\delta(I_m)$. At each information set I_m, the agent updates his belief $R(H|I_m)$.[7]

Since G and G^* have the same stopping and hiring rules, the following feasibility constraint must hold:

$$R(H|I^*) = \sum_{I_m \in I(G)} R(H|I_m)\delta(I_m)$$

$\forall H \in \mathcal{H}$. Since G and G^* are using the same hiring rule, the agent will be hired with same probability under the two mechanisms when facing the same history if he uses the same

[7] Note that if an agent is not told anything, he will still update his belief based on the rules as well as the fact that he is not told anything. For example, the agent knows that under mechanism G' with probability 0.5 the principal will tell the first agent that he's the first to be visited while with probability 1 she will tell nothing to anyone else, then given the fact that the agent is not told anything, he will update his belief about the calendar time.

strategy. Given that everyone else acquires information and report truthfully, conditional on history H, let V_H^α and V_H^β denote the probabilities of being hired when reporting truthfully and misreporting after acquiring information, respectively.

Since G is IE, at each information set I_m, we must have

$$\text{IC}_m\colon \sum_{H\in\mathcal{H}} \left(V_H^\alpha - V_H^\beta\right) R(H|I_m) > 0$$

$$\text{IR}_m\colon \frac{1}{2}\sum_{H\in\mathcal{H}} \left(V_H^\alpha - V_H^\beta\right) R(H|I_m) \geq c$$

Then under G^*,

$$\begin{aligned}
&\sum_{H\in\mathcal{H}} \left(V_H^\alpha - V_H^\beta\right) R(H|I^*) \\
=&\sum_{H\in\mathcal{H}} \left(V_H^\alpha - V_H^\beta\right) \sum_{m=1}^{M} R(H|I_m)\delta(I_m) \\
=&\sum_{m=1}^{M}\Big(\sum_{H\in\mathcal{H}} \left(V_H^\alpha - V_H^\beta\right) R(H|I_m)\Big)\delta(I_m) \\
>&2c\sum_{m=1}^{M}\delta(I_m) = 2c
\end{aligned}$$

Therefore, the IR and IC constraints are satisfied under G^*, and hence G^* is IC and IR, and hence IE. ■

A.2 Proof of Lemma 2.

Since G^1 and G^2 have the same stopping rule, agents share same beliefs about histories under the two mechanisms. Given that all other agents acquire information and report truthfully when visited, we consider the IR and IC constraints of the current agent.

Upon being visited, with probability θ the agent's signal matches the efficient action; conditional on this case, the probability of being hired when reporting truthfully is $\sum_{j=k}^{N}\frac{\sigma(j)}{j}$ where $\sigma(j)$ is the conditional probability that there are j agents who recommend the efficient action when the principal stops visiting. Still conditional on the case that his signal matches an efficient action, if he chooses to misreport, he will be hired with probability

$$\frac{\epsilon_1}{k} + \frac{\epsilon_2}{N-k+1}$$

where ϵ_1 is the conditional probability that the following scenario takes place: the agent's signal is different from the $\mathcal{S}_P$, and when the agent misreports, $a_{\mathcal{S}_P}$ becomes efficient; ϵ_2 is the conditional probability of the following case: the agent's signal is the same as $\mathcal{S}_P$, and when the agent misreports, his recommended action happens to be efficient again. Note that all probabilities we mention above do not depend on the hiring rule because from the agent's perspective, since there is no information about the timeline, anyone who recommends an efficient action has the same chance of being hired.

Similarly, conditional on the case that the agent's signal doesn't match the efficient action, the probability of being hired also doesn't depend on the hiring rule. Note that when reporting truthfully, the conditional probability of being hired is 0; the conditional probability of being hired when misreporting is $\sum_{j=k}^{N} \frac{\sigma'(j)}{j}$ where $\sigma'(j)$ is the conditional probability that there are $j-1$ other agents who recommend the efficient action when the principal stops visiting.

As a result, upon being visited, if acquiring information and reporting truthfully, the agent will be hired with probability

$$\theta \cdot \sum_{j=k}^{N} \frac{\sigma(j)}{j}$$

and if acquiring information but misreporting, the agent will be hired with probability

$$\theta \cdot \left(\frac{\epsilon_1}{k} + \frac{\epsilon_2}{N-k+1}\right) + (1-\theta) \sum_{j=k}^{N} \frac{\sigma'(j)}{j}$$

Therefore, none of the terms of the IR or IC constraints depends on the hiring rule, which implies that the two mechanisms are essentially equivalent. ■

A.3 Proof of Proposition 1.

Since $q = q'$, now we have

$$q(1-p)^{N-2k+2} < (1-q)p^{N-2k+2}$$

$$q(1-p)^{N-2k} > (1-q)p^{N-2k}$$

Let $c_0 = \frac{r}{2}(V^\alpha_{G_0} - V^\beta_{G_0}) > 0$. We only need to show that $V^\alpha_{G_0} > V^\beta_{G_0}$.[8]

Define (D, x, y) as the situation where $D = 1\{\mathcal{S}_P = \mathcal{S}_i\}$, and x is the number of agents who receive the same signal and y is the number of agents who receive the different signal, and $x + y = N - 1$. Note that there are $2N$ different situations. Divide the $2N$ situations into N groups: $\{(0, y, x), (1, x, y)\}_{x\in\{0,1,\cdots,N-1\}}$.

Note that situation $(0, y, x)$ happens with probability

$$\begin{aligned} P(0, y, x) &= C^x_{N-1}\big[p \cdot p^y(1 - p)^x(1 - q) + (1 - p)(1 - p)^y p^x q\big] \\ &= C^x_{N-1}\big[qp^x(1 - p)^{y+1} + (1 - q)p^{y+1}(1 - p)^x\big] \end{aligned}$$

Situation $(1, x, y)$ happens with probability

$$\begin{aligned} P(1, x, y) &= C^x_{N-1}\big[p \cdot p^x(1 - p)^y q + (1 - p)(1 - p)^x p^y(1 - q)\big] \\ &= C^x_{N-1}\big[qp^{x+1}(1 - p)^y + (1 - q)p^y(1 - p)^{x+1}\big] \end{aligned}$$

Therefore, group $\{(0, y, x), (1, x, y)\}$ happens with probability

$$P_x = C^x_{N-1}\big[qp^x(1 - p)^y + (1 - q)p^y(1 - p)^x\big]$$

Then conditional on group $\{(0, y, x), (1, x, y)\}$, situation $(0, y, x)$ happens with probability $P^0_x = \frac{P(0,y,x)}{P_x}$, and situation $(1, x, y)$ happens with probability $P^1_x = \frac{P(1,x,y)}{P_x}$.

Define $K := \big\{(0, N - k, k - 1), (1, k - 1, N - k)\big\}$ as the pivotal group. Note that the pivotal group happens with probability $P_K = P_{k-1}$.

Lemma 3. *Conditional on any group $\{(0, y, x), (1, x, y)\}$ that is not pivotal, agent i is hired with a strictly higher probability by reporting truthfully.*

Proof of Lemma 3.

Case I: $x \le k - 2$. Then $2k - 2x - 3 \ge 1$. If reporting truthfully, then agent i is hired with probability $P^0_x/(y + 1)$; if misreporting, agent i is hired with probability $P^1_x/(y + 1)$.

[8] By symmetry, one can infer that $V^\alpha_{G_0} = \frac{1}{N}$. We didn't emphasize this because it doesn't play a role in the entire proof.

Note that

$$\begin{aligned}
P(0,y,x)-P(1,x,y) &= C_{N-1}^{x}\big[qp^x(1-p)^y(1-2p)+(1-q)p^y(1-p)^x(2p-1)\big] \\
&= C_{N-1}^{x}(2p-1)p^x(1-p)^x\big[(1-q)p^{y-x}-q(1-p)^{y-x}\big] \\
&= C_{N-1}^{x}(2p-1)p^x(1-p)^x\big[(1-q)p^{N-2x-1}-q(1-p)^{N-2x-1}\big] \\
&= C_{N-1}^{x}(2p-1)p^x(1-p)^x p^{2k-2x-3}\big[(1-q)p^{N-2k+2}-\frac{q(1-p)^{N-2x-1}}{p^{2k-2x-3}}\big] \\
&> C_{N-1}^{x}(2p-1)p^x(1-p)^x p^{2k-2x-3}\big[q(1-p)^{N-2k+2}-\frac{q(1-p)^{N-2x-1}}{p^{2k-2x-3}}\big] \\
&= C_{N-1}^{x}(2p-1)p^x(1-p)^x q(1-p)^{N-2k+2}\big[p^{2k-2x-3}-(1-p)^{2k-2x-3}\big] > 0
\end{aligned}$$

Hence, $P_x^0/(y+1) - P_x^1/(y+1) > 0$.

Case II: $x \geq k$. Then $2k-2x-1 \leq -1$. By reporting truthfully, agent i is hired with probability $P_x^1/(x+1)$; if misreporting, agent i is hired with probability $P_x^0/(x+1)$. Similarly,

$$\begin{aligned}
P(0,y,x)-P(1,x,y) &= C_{N-1}^{x}(2p-1)p^x(1-p)^x\big[(1-q)p^{N-2x-1}-q(1-p)^{N-2x-1}\big] \\
&= C_{N-1}^{x}(2p-1)p^x(1-p)^x p^{2k-2x-1}\big[(1-q)p^{N-2k}-\frac{q(1-p)^{N-2x-1}}{p^{2k-2x-1}}\big] \\
&< C_{N-1}^{x}(2p-1)p^x(1-p)^x p^{2k-2x-1}\big[q(1-p)^{N-2k}-\frac{q(1-p)^{N-2x-1}}{p^{2k-2x-1}}\big] \\
&= C_{N-1}^{x}(2p-1)p^x(1-p)^x q(1-p)^{N-2k}\big[p^{2k-2x-1}-(1-p)^{2k-2x-1}\big] < 0
\end{aligned}$$

Hence, $P_x^1/(x+1) - P_x^0/(x+1) > 0$.

That is, under both cases, agent i is hired with a strictly higher probability when reporting truthfully. □

If $k = [\frac{N}{2}]+1$, then it has to be either $N = 2k-1$ or $N = 2k-2$. However, if $N = 2k-2$, then it requires at most $k-1$ agents recommending action $a_{\mathcal{S}_P}$ to make action $a_{\mathcal{S}_P}$ efficient, which leads to a contradiction. Therefore, we infer that $N = 2k-1$, and $q < p$. Then, the pivotal group is $\{(0, k-1, k-1), (1, k-1, k-1)\}$. Conditional on the pivotal group, agent i is hired with probability $1/k$ regardless of what he recommends. Moreover, since $N = 2k-1$ and $N \geq 2$, we infer $N \geq 3$, which implies that not being pivotal happens with a positive probability. Then together with Lemma 3, after taking the expectation, we conclude that $V^{\alpha}_{G_0} > V^{\beta}_{G_0}$.

Now consider any $k \in \{1, 2, \cdots, [\frac{N}{2}]\}$. We consider the following set of groups:

$$L := \Big\{\big(0, N-\ell, \ell-1\big), \big(1, \ell-1, N-\ell\big)\Big\}_{\ell\in\{k+1,\cdots,N-k+1\}}$$

The probability that the situation lies in L is $P_L = \sum_{\ell=k+1}^{N-k+1} P_{\ell-1}$. Conditional on set L, denote V^{α}_L and V^{β}_L as the probabilities of being hired given that agent i is reporting truthfully and misreporting, respectively. Note that

$$\begin{aligned} V^{\alpha}_L \cdot P_L &= \sum_{l=k+1}^{N-k+1} P_{\ell-1}\frac{P^1_{\ell-1}}{\ell} = \sum_{l=k+1}^{N-k+1} \frac{P(1,\ell-1,N-\ell)}{\ell} \\ &= \sum_{l=k+1}^{N-k+1} \frac{C^{\ell-1}_{N-1}\big[qp^{\ell}(1-p)^{N-\ell} + (1-q)p^{N-\ell}(1-p)^{\ell}\big]}{\ell} \end{aligned}$$

Similarly, we have

$$V^{\beta}_L \cdot P_L = \sum_{l=k+1}^{N-k+1} P_{\ell-1}\frac{P^0_{\ell-1}}{\ell} = \sum_{l=k+1}^{N-k+1} \frac{C^{\ell-1}_{N-1}\big[qp^{\ell-1}(1-p)^{N-\ell+1} + (1-q)p^{N-\ell+1}(1-p)^{\ell-1}\big]}{\ell}$$

Therefore,

$$\begin{aligned} \big(V^{\alpha}_L - V^{\beta}_L\big) \cdot P_L &= \sum_{l=k+1}^{N-k+1} \frac{C^{\ell-1}_{N-1}\big[qp^{\ell}(1-p)^{N-\ell} + (1-q)p^{N-\ell}(1-p)^{\ell}\big]}{\ell} \\ &\quad - \sum_{l=k+1}^{N-k+1} \frac{C^{\ell-1}_{N-1}\big[qp^{\ell-1}(1-p)^{N-\ell+1} + (1-q)p^{N-\ell+1}(1-p)^{\ell-1}\big]}{\ell} \\ &= \sum_{l=k+1}^{N-k+1} \frac{C^{\ell-1}_{N-1}}{\ell}(2p-1)\Big[qp^{\ell-1}(1-p)^{N-\ell} - (1-q)p^{N-\ell}(1-p)^{\ell-1}\Big] \end{aligned}$$

Now consider the set $L \cup K$, which happens with probability $P_{L\cup K} = \sum_{j=k}^{N-k+1} P_{j-1}$. Conditional on $L \cup K$, denote $V^{\alpha}_{L\cup K}$ and $V^{\beta}_{L\cup K}$ as the probabilities of being hired given that agent i is reporting truthfully and misreporting, respectively. Also define V^{α}_K and V^{β}_K in a similar way. Then,

$$V^{\alpha}_{L\cup K} \cdot P_{L\cup K} = V^{\alpha}_K \cdot P_{k-1} + V^{\alpha}_L \cdot P_L$$

$$V^{\beta}_{L\cup K} \cdot P_{L\cup K} = V^{\beta}_{K} \cdot P_{k-1} + V^{\beta}_{L} \cdot P_{L}$$

To show that $V^{\alpha}_{L\cup K} > V^{\beta}_{L\cup K}$, we only need to show $\left(V^{\alpha}_{L} - V^{\beta}_{L}\right) \cdot P_{L} > \left(V^{\beta}_{K} - V^{\alpha}_{K}\right) \cdot P_{k-1}$. Note that

$$\begin{aligned}
\left(V^{\beta}_{K} - V^{\alpha}_{K}\right) \cdot P_{k-1} &= \frac{P(1, k-1, N-k)}{N-k+1} + \frac{P(0, N-k, k-1)}{k} \\
&\quad - \frac{P(1, k-1, N-k)}{k} - \frac{P(0, N-k, k-1)}{N-k+1} \\
&= \left(\frac{1}{k} - \frac{1}{N-k+1}\right)\left[P(0, N-k, k-1) - P(1, k-1, N-k)\right] \\
&= \left(\frac{C^{k-1}_{N-1}}{k} - \frac{C^{k-1}_{N-1}}{N-k+1}\right)(2p-1)\left[(1-q)p^{N-k}(1-p)^{k-1} - qp^{k-1}(1-p)^{N-k}\right]
\end{aligned}$$

Next, we prove the following two inequalities:

$$qp^{\ell-1}(1-p)^{N-\ell} - (1-q)p^{N-\ell}(1-p)^{\ell-1} \geq (1-q)p^{N-k}(1-p)^{k-1} - qp^{k-1}(1-p)^{N-k} \quad (1)$$

$$\sum_{\ell=k+1}^{N-k+1} \frac{C^{\ell-1}_{N-1}}{\ell} \geq \frac{C^{k-1}_{N-1}}{k} - \frac{C^{k-1}_{N-1}}{N-k+1} \quad (2)$$

Proof of inequality (1).

Note that inequality (1) is equivalent to

$$qp^{k-1}(1-p)^{N-\ell}\left[p^{\ell-k} + (1-p)^{\ell-k}\right] \geq (1-q)p^{N-\ell}(1-p)^{k-1}\left[p^{\ell-k} + (1-p)^{\ell-k}\right]$$

which is also equivalent to

$$q(1-p)^{N-k-\ell+1} \geq (1-q)p^{N-k-\ell+1}$$

which can also be rewritten as

$$q(1-p)^{N-k-\ell+1}(1-p)^{\ell-k-1} \geq (1-q)p^{N-k-\ell+1}(1-p)^{\ell-k-1}$$

This is true because

$$q(1-p)^{N-k-\ell+1}(1-p)^{\ell-k-1} = q(1-p)^{N-2k} \geq (1-q)p^{N-2k} \geq (1-q)p^{N-k-\ell+1}(1-p)^{\ell-k-1}$$

This completes the proof of inequality (1). Note that inequality (1) is binding if and only if $\ell = k+1$ and $q(1-p)^{N-2k} = (1-q)p^{N-2k}$. □

Proof of inequality (2).

Note that for any $\ell \in \{k+1, \cdots, N-k+1\}$, we must have

$$\frac{C_{N-1}^{N-\ell-1}}{N-\ell} = \frac{(N-1)!}{(N-\ell)(N-\ell-1)!\ell!} = \frac{(N-1)!}{(N-\ell)!(\ell-1)!\ell} = \frac{C_{N-1}^{\ell-1}}{\ell}$$

Since $k \leq [\frac{N}{2}]$, we only need to prove the above inequality for all $N \geq 2k$. If $N \geq 2k+1$, then

$$LHS > \frac{C_{N-1}^{N-k-1}}{N-k} = \frac{C_{N-1}^{k-1}}{k} > RHS$$

If $N = 2k$, then

$$LHS = \frac{C_{2k-1}^{k}}{k+1} = \frac{C_{2k-1}^{k-1}}{k+1}$$

$$RHS = \frac{C_{2k-1}^{k-1}}{k} - \frac{C_{2k-1}^{k-1}}{k+1}$$

Note that for any $k \geq 1$,

$$LHS - RHS = C_{2k-1}^{k-1}(\frac{2}{k+1} - \frac{1}{k}) \geq 0$$

This proves inequality (2), and we can see it's binding if and only if $N = 2k$ and $\frac{2}{k+1} = \frac{1}{k}$, that is, $k = 1$ and $N = 2$. □

Combine inequalities (1) and (2), we get $V_{L\cup K}^{\alpha} \geq V_{L\cup K}^{\beta}$, and it's binding if and only if $k = 1$, $N = 2$, and $q = \frac{1}{2}$, which contradicts the assumption of $q > \frac{1}{2}$. Therefore, we must have $V_{L\cup K}^{\alpha} > V_{L\cup K}^{\beta}$. Then, together with Lemma 3, since $P_{L\cup K} > 0$, we conclude that $V_{G_0}^{\alpha} > V_{G_0}^{\beta}$. ■

A.4 Proof of Theorem 1.

Define $G_0' \in \mathcal{G}^*$ as the sequential mechanism with

(i) stopping rule: never stops until all agents are visited;

(ii) hiring rule: let T be the period at the end of which the principal first learns the efficient action; the agents who recommend the efficient action before or at period T are hired with equal probabilities.

By Lemma 2, G_0' is essentially equivalent to G_0. Under G_0', when an agent is being visited, there are two possible cases: (i) an efficient action has been reached, or (ii) no efficient action has been reached yet.

Conditional on case (i), the agent will never be hired and hence will be indifferent between telling the truth or not given that he has already acquired the information.

Conditional on case (ii), the agent will find himself the same as under G_1 upon being visited by the principal.

Therefore, we have

$$V_{G_0}^{\alpha} - V_{G_0}^{\beta} = \lambda \cdot 0 + (1-\lambda)\big(V_{G_1}^{\alpha} - V_{G_1}^{\beta}\big)$$

where $\lambda \in (0,1)$ denotes the probability that case (i) happens. This implies that $V_{G_1}^{\alpha} - V_{G_1}^{\beta} > V_{G_0}^{\alpha} - V_{G_0}^{\beta}$. By Proposition 1, we can take $c_1 = \frac{r}{2}\big(V_{G_1}^{\alpha} - V_{G_1}^{\beta}\big) > c_0$ such that G_1 is IE if and only if $c \leq c_1$.

Now we prove part (2) of the theorem. If there exists an IE mechanism G when $c > c_1$, then by Lemma 1, we can assume $G \in \mathcal{G}^*$. Modify G to G' such that the stopping rule doesn't change while the hiring rule is the same as G_0'. With similar arguments, we can show that $V_{G_1}^{\alpha} - V_{G_1}^{\beta} > V_{G'}^{\alpha} - V_{G'}^{\beta}$. This contradicts to G' being IE when $c > c_1$. ■

A.5 Proof of Proposition 2.

Given that $q \leq \frac{1+p}{3} < p < q'$, since $N = 3$, it must be $k = 1$. Then

$$\begin{aligned}\big(V_L^{\alpha} - V_L^{\beta}\big) \cdot P_L =& \frac{C_2^1}{2}(2p-1)\Big[qp(1-p) - (1-q)p(1-p)\Big] \\ &+ \frac{C_2^2}{3}(2p-1)\Big[qp^2 - (1-q)(1-p)^2\Big]\end{aligned}$$

$$\big(V_K^{\alpha} - V_K^{\beta}\big) \cdot P_0 = \Big(\frac{C_2^0}{1} - \frac{C_2^0}{3}\Big)(2p-1)\Big[q(1-p)^2 - (1-q)p^2\Big]$$

Therefore,

$$\big(V_L^{\alpha} - V_L^{\beta}\big) \cdot P_L + \big(V_K^{\alpha} - V_K^{\beta}\big) \cdot P_0 = (2p-1)(q-p) + \frac{(2p-1)^2}{3} = (2p-1)(q - \frac{p+1}{3}) \leq 0$$

This implies that for any $c > 0$, G_0 is not IE. Then by Lemma 4, there exists no IE mechanism. The "if" part is done. The "only if" part is straightforward given the expression in the "if" part as well as Proposition 5: given that there exists no IE mechanism for any $c > 0$, we infer that $q < p < q'$, and hence $k = 1$. Then we have the above expression again. We need $(2p-1)(q - \frac{p+1}{3}) \leq 0$, which requires $q \leq \frac{1+p}{3}$. ■

A.6 Proof of Proposition 3.

Take $N \geq 3$ and fix $p \in (\frac{1}{2}, 1)$. Take q' sufficiently close to $\frac{p^N}{p^N+(1-p)^N}$. Then we must have $k = 1$. Use the expressions we obtain in proof of Theorem 2, we only need to show that there exists $q < p$ such that

$$(p-q)\sum_{\ell=1}^{N-1}\frac{C_{N-1}^{\ell-1}}{\ell}p^{\ell-1}(1-p)^{N-\ell-1} \geq \frac{2p-1}{N}\sum_{\ell=1}^{N-1}p^{\ell-1}(1-p)^{N-\ell-1}$$

Note that

$$LHS \geq (p-q)\sum_{\ell=1}^{N-1}p^{\ell-1}(1-p)^{N-\ell-1}$$

So we only need to show that there exists $q < p$ such that $p - q \geq \frac{2p-1}{N}$ given any $N \geq 3$. Simply take any $q \in \left(\frac{1}{2}, \frac{(N-2)p+1}{N}\right]$. Note that for any $p \in (\frac{1}{2}, 1)$ and $N \geq 3$, the condition $\frac{1}{2} < \frac{(N-2)p+1}{N} < p$ is naturally satisfied. Therefore, we conclude that if

$$q \in \left(\frac{1}{2}, \frac{(N-2)p+1}{N}\right]$$

$$q' = \frac{p^N}{p^N+(1-p)^N} - \epsilon$$

then there exists no IE mechanism for any $c > 0$. ■

A.7 Proof of Theorem 2.

We only need to show that Proposition 1 holds when N is large enough, and then Theorem 1 holds automatically. Since $p < q'$, we have $N \geq 2k$, and hence conditional on any group with $x \geq \frac{N-1}{2}$, it's strictly better for the agent to report truthfully. Now consider the groups in L. We want to show that for large enough N, there must be

$$\left(V_L^\alpha - V_L^\beta\right) \cdot P_L + \left(V_K^\alpha - V_K^\beta\right) \cdot P_{k-1} > 0$$

Note that

$$\begin{aligned}
&\frac{\left(V_L^\alpha - V_L^\beta\right) \cdot P_L + \left(V_K^\alpha - V_K^\beta\right) \cdot P_{k-1}}{(2p-1) \cdot p^{k-1} \cdot (1-p)^{k-1}} \\
=&\sum_{\ell=k}^{N-k} \frac{C_{N-1}^{\ell-1}}{\ell} \left[qp^{\ell-k}(1-p)^{N-\ell-k+1} - (1-q)p^{N-\ell-k+1}(1-p)^{\ell-k}\right] \\
&+ \frac{C_{N-1}^{k-1}}{N-k+1}\left[p^{N-2k+1} - (1-p)^{N-2k+1}\right] \\
=&\sum_{\ell=k}^{N-k} \frac{C_{N-1}^{\ell-1}}{\ell} q(1-p) \cdot p^{\ell-k}(1-p)^{N-\ell-k} - \sum_{\ell=k}^{N-k} \frac{C_{N-1}^{\ell-1}}{\ell} p(1-q) \cdot p^{N-\ell-k}(1-p)^{\ell-k} \\
&+ \frac{C_{N-1}^{k-1}}{N-k+1}(2p-1) \sum_{\ell=k}^{N-k} p^{N-l-k}(1-p)^{\ell-k} \\
=&\sum_{\ell=k}^{N-k} \frac{C_{N-1}^{\ell-1}}{\ell} q(1-p) \cdot p^{\ell-k}(1-p)^{N-\ell-k} - \sum_{\ell=k}^{N-k} \frac{C_{N-1}^{N-\ell-1}}{N-\ell} p(1-q) \cdot p^{N-\ell-k}(1-p)^{\ell-k} \\
&+ \frac{C_{N-1}^{k-1}}{N-k+1}(2p-1) \sum_{\ell=k}^{N-k} p^{N-l-k}(1-p)^{\ell-k} \\
=&\sum_{\ell=k}^{N-k} \frac{C_{N-1}^{\ell-1}}{\ell} (q-p) \cdot p^{\ell-k}(1-p)^{N-\ell-k} + \frac{C_{N-1}^{k-1}}{N-k+1}(2p-1) \sum_{\ell=k}^{N-k} p^{N-l-k}(1-p)^{\ell-k}
\end{aligned}$$

Since $q < p$, we want to show the following: for large enough N,

$$\frac{2p-1}{p-q} \cdot \frac{C_{N-1}^{k-1}}{N-k+1} \sum_{\ell=k}^{N-k} p^{N-l-k}(1-p)^{\ell-k} > \sum_{\ell=k}^{N-k} \frac{C_{N-1}^{\ell-1}}{\ell} \cdot p^{\ell-k}(1-p)^{N-\ell-k}$$

that is, we want to show

$$\frac{2p-1}{p-q} > \lim_{N\to\infty} \frac{\sum_{\ell=k}^{N-k} \frac{C_{N-1}^{\ell-1}}{\ell} \cdot p^{\ell-k}(1-p)^{N-\ell-k}}{\frac{C_{N-1}^{k-1}}{N-k+1} \sum_{\ell=k}^{N-k} p^{N-l-k}(1-p)^{\ell-k}}$$

Note that

$$\lim_{N\to\infty}\frac{k}{N}=\frac{1}{2}$$

Then for any $\ell\in[k,N-k]$

$$\lim_{N\to\infty}\frac{\frac{C_{N-1}^{\ell-1}}{\ell}}{\frac{C_{N-1}^{k-1}}{N-k+1}}=1$$

Therefore,

$$\lim_{N\to\infty}\frac{\sum_{\ell=k}^{N-k}\frac{C_{N-1}^{\ell-1}}{\ell}\cdot p^{\ell-k}(1-p)^{N-\ell-k}}{\frac{C_{N-1}^{k-1}}{N-k+1}\sum_{\ell=k}^{N-k}p^{N-l-k}(1-p)^{\ell-k}}=1<\frac{2p-1}{p-q}$$

This shows that Proposition 1 holds for large enough N. Then by the same arguments as in Appendix A.4, one can show that Theorem 1 holds whenever Proposition 1 holds. ∎

B Additional Results.

In this section, we present some results that are skipped in the main text. The following Lemma 4 is important for us to understand the fact that, although the sequential mechanism G_1 can optimally overcome moral hazard, it is not better than the static mechanism G_0 in terms of resolving adverse selection. As a result, when discussing strategic issues, it's enough for us to simply focus on G_0.

Lemma 4. *Given any problem, the following are equivalent:*

(1) there exists no informationally efficient mechanism for any $c>0$;

(2) G_0 is not informationally efficient for any $c>0$;

(3) G_1 is not informationally efficient for any $c>0$.

Proof of Lemma 4.

"(1)⇒(3)" is trivial.

"(3)⇒(2)" is also straightforward by repeating part (1) of the proof of Theorem 1.

Now we show the "(2)⇒(1)". Take any $c>0$. Given that G_0 is not IE, suppose that there exists an IE mechanism. By Lemma 1, we can assume that there is an IE mechanism $G'\in\mathcal{G}^*$. Modify G_0 to G_0' such that G_0' and G' have the same hiring rule while G_0 and G_0' have the same stopping rule (similar to proof of Theorem 1). By Lemma 2, G_0 and G_0' are essentially equivalent, and hence G_0' is not IE, i.e., $V_{G_0'}^{\beta}\geq V_{G_0'}^{\alpha}$. Note that under G_0', when visited, there are two possible cases: (i) the principal should have stopped visiting given the current history under mechanism G' (so he wouldn't be visited if it's under G'), or (ii) the principal should also keep visiting if it's under mechanism G'. Each case happens with a positive probability. Conditional on case (i), the agent is indifferent. Therefore, we infer that conditional on case (ii), the agent will be hired with a weakly higher probability when misreporting. Note that the agent has the exactly same belief when visited under G' as in case (ii) under G'_0. Therefore, we infer $V^{\beta}_{G'} \geq V^{\alpha}_{G'}$, contradicting G' being IE. ■

The following Proposition 4 explains why we could assume $q'(1-p)^{N-2k} > (1-q')p^{N-2k}$ without loss.

Proposition 4. *Suppose that $q'(1-p)^{N'-2k} = (1-q')p^{N'-2k}$. Define $N = N'-1$. Then given $c > 0$, G_1 is informationally efficient for problem (p, q, q', N) if and only if G_1 is informationally efficient for problem (p, q, q', N').*

Proof of Proposition 4.

Note that for problem (p, q, q', N), under mechanism G_1, the principal will never visit all N agents because after visiting $N-1$ agents, an efficient action must have been reached, so she will stop visiting based on the stopping rule of G_1. Therefore, when an agent is visited, his belief is exactly the same across these two problems. ■

The following result shows several sufficient conditions that can guarantee the existence of an IE mechanism when $c > 0$ is sufficiently small.

Proposition 5. *Given any problem with (i) $p \leq q < q'$, or (ii) $q < q' \leq p$, or (iii) $N = 2k$ and $q < p < q'$, there exist $c_1 > c_0 > 0$ such that*

(1) G_0 is informationally efficient if and only if $c \in (0, c_0]$;

(2) G_1 is informationally efficient if and only if $c \in (0, c_1]$;

(3) there exists no informationally efficient mechanism if $c > c_1$.

Proof of Proposition 5.

We only need to show that Proposition 1 holds under each condition, and then with arguments similar to those in Appendix A.4, we can infer that Theorem 1 also holds under each condition. To show that Proposition 1 holds, we use a proof structure similar to Appendix A.3 and also its notations.

Now k is determined by q' instead of q. Note that Lemma 3 no longer holds in general but we can still think about the two cases separately: $x \leq k-2$, and $x \geq k$.

Since $q < q'$, we must have

$$(1-q)p^{N-2k+2} > (1-q')p^{N-2k+2} > q'(1-p)^{N-2k+2} > q(1-p)^{N-2k+2}$$

Therefore, for $x \leq k-2$, with the same argument as in the proof of Lemma 3, we must still have $P(0,y,x) - P(1,x,y) > 0$. That is, conditional on any group with $x \leq k-2$, reporting truthfully brings a strictly higher probability of being hired. For $x \geq k$, this result no longer holds.

From now on, we prove that Proposition 1 holds under each of the conditions.

Part (1):

Since $\frac{1}{2} < p \leq q < q'$, we must have $N \geq 2k$. For any $x \geq \frac{N-1}{2}$, we must have

$$\begin{aligned} P(0,y,x) - P(1,x,y) &= C_{N-1}^{x}(2p-1)p^{x}(1-p)^{x}\left[(1-q)p^{N-2x-1} - q(1-p)^{N-2x-1}\right] \\ &\leq C_{N-1}^{x}(2p-1)p^{x}(1-p)^{x}\left[(1-p)p^{N-2x-1} - p(1-p)^{N-2x-1}\right] < 0 \end{aligned}$$

which implies that conditional on any group with $x \geq \frac{N-1}{2}$, it's strictly better for the agent to report truthfully than misreporting.

Now consider the groups in L again. Since $N - k \geq \frac{N-1}{2}$, we are done if we can show that, conditional on L, there is a higher probability of being hired if reporting truthfully. To show this, we again need to show that $(V_L^{\alpha} - V_L^{\beta})P_L + (V_K^{\alpha} - V_K^{\beta})P_{k-1} > 0$. Note that

$$\begin{aligned} \left(V_L^{\alpha} - V_L^{\beta}\right) \cdot P_L &= \sum_{l=k+1}^{N-k+1} \frac{C_{N-1}^{\ell-1}}{\ell}(2p-1)\left[qp^{\ell-1}(1-p)^{N-\ell} - (1-q)p^{N-\ell}(1-p)^{\ell-1}\right] \\ &\geq \sum_{l=k+1}^{N-k+1} \frac{C_{N-1}^{\ell-1}}{\ell}(2p-1)\left[p^{\ell}(1-p)^{N-\ell} - p^{N-\ell}(1-p)^{\ell}\right] \end{aligned}$$

$$\begin{aligned} \left(V_K^{\alpha} - V_K^{\beta}\right) \cdot P_{k-1} &= \left(\frac{C_{N-1}^{k-1}}{k} - \frac{C_{N-1}^{k-1}}{N-k+1}\right)(2p-1)\left[qp^{k-1}(1-p)^{N-k} - (1-q)p^{N-k}(1-p)^{k-1}\right] \\ &\geq \left(\frac{C_{N-1}^{k-1}}{k} - \frac{C_{N-1}^{k-1}}{N-k+1}\right)(2p-1)\left[p^{k}(1-p)^{N-k} - p^{N-k}(1-p)^{k}\right] \end{aligned}$$

Hence,

$$\begin{aligned}&\left(V_L^\alpha - V_L^\beta\right)\cdot P_L + \left(V_K^\alpha - V_K^\beta\right)\cdot P_{k-1}\\ \geq &\sum_{l=k}^{N-k+1}\frac{C_{N-1}^{\ell-1}}{\ell}(2p-1)\Big[p^\ell(1-p)^{N-\ell} - p^{N-\ell}(1-p)^\ell\Big]\\ &+\frac{C_{N-1}^{k-1}}{N-k+1}(2p-1)\Big[p^{N-k}(1-p)^k - p^k(1-p)^{N-k}\Big]\end{aligned}$$

Since

$$\frac{C_{N-1}^{N-\ell-1}}{N-\ell} = \frac{C_{N-1}^{\ell-1}}{\ell}$$

we have

$$\frac{C_{N-1}^{\ell-1}}{\ell}\Big[p^\ell(1-p)^{N-\ell} - p^{N-\ell}(1-p)^\ell\Big] = \frac{C_{N-1}^{N-\ell-1}}{N-\ell}\Big[p^{N-\ell}(1-p)^\ell - p^\ell(1-p)^{N-\ell}\Big]$$

which implies

$$\sum_{l=k}^{N-k}\frac{C_{N-1}^{\ell-1}}{\ell}(2p-1)\Big[p^\ell(1-p)^{N-\ell} - p^{N-\ell}(1-p)^\ell\Big] = 0$$

Therefore,

$$\begin{aligned}&\left(V_L^\alpha - V_L^\beta\right)\cdot P_L + \left(V_K^\alpha - V_K^\beta\right)\cdot P_{k-1}\\ \geq &\frac{C_{N-1}^{k-1}}{N-k+1}(2p-1)\Big[p^{N-k+1}(1-p)^{k-1} - p^{k-1}(1-p)^{N-k+1}\Big]\\ &+\frac{C_{N-1}^{k-1}}{N-k+1}(2p-1)\Big[p^{N-k}(1-p)^k - p^k(1-p)^{N-k}\Big] > 0\end{aligned}$$

This completes the proof for part (1).

Parts (2) & (3):

If $q < q' = p$, then according to our assumption, we only need to consider $N = 2k$. If $q < q' < p$, we have either $N = 2k$ or $N = 2k-1$. Part (3) itself requires $N = 2k$. One can show that Lemma 3 now holds because there must be

$$(1-q)p^{N-2x-1} < q(1-p)^{N-2x-1}$$

for any $x \geq k$.

If $N = 2k-1$, then $k \geq 2$, and $\left(V_K^\alpha - V_K^\beta\right)\cdot P_{k-1} = 0$. Since $k \geq 2$, groups with $x \leq k-2$

happens with a strictly positive probability; together with Lemma 3, we are done.

If $N = 2k$, one can easily check that both inequalities (1) and (2) in Appendix A.3 hold. We are done. ■

The next result shows a general method of identifying more problems leading to adverse selection given that one such problem is already identified. This can also be regarded as a comparative statics analysis.

Proposition 6. *Suppose that for problem $(p, \underline{q}, \bar{q}, N)$ there exists no informationally efficient mechanism for any $c > 0$. Then for any problem (p, q, q', N) with $q \in (\frac{1}{2}, \underline{q}]$ and $q' \in \big[\bar{q}, \frac{p^N}{p^N+(1-p)^N}\big)$, there exists no informationally efficient mechanism for any $c > 0$.*

Proof of Proposition 6.

For any problem $(p, q, \bar{q}, N)$ with $q \in (\frac{1}{2}, \underline{q}]$, we want to show that $V^{\beta}_{G_0} \geq V^{\alpha}_{G_0}$. Given that $V^{\beta}_{G_0} \geq V^{\alpha}_{G_0}$ when $q = \underline{q}$, we only need to show that the value of $V^{\beta}_{G_0} - V^{\alpha}_{G_0}$ increases as q decreases. Recall the expressions in the proof of Proposition 1. Note that for any group with $x \geq k-1$, a smaller q leads to a higher value of $(V^{\beta}_x - V^{\alpha}_x) \cdot P_x$ where V^{α}_x denotes the probability of being hired conditional on group with x when reporting truthfully. For each $i \in \{0, 1, \cdots, k-2\}$, put these two groups together: group with $x = i$, and group with $x = N-1-i$. One can show that the value of $(V^{\beta}_i - V^{\alpha}_i) \cdot P_i + (V^{\beta}_{N-1-i} - V^{\alpha}_{N-1-i}) \cdot P_{N-1-i}$ equals to

$$\frac{C^i_{N-1}(2p-1)\Big(p^i(1-p)^{N-i-1} - p^{N-i-1}(1-p)^i\Big)}{N-i}$$

which is constant at q. Then, since for each group with $x \in \{k-1, \cdots, N-k\}$, the value of $(V^{\beta}_x - V^{\alpha}_x) \cdot P_x$ increases as q decreases, we conclude that the value of $V^{\beta}_{G_0} - V^{\alpha}_{G_0}$ increases as q decreases.

Now, for any problem $(p, \underline{q}, q', N)$ with $q' \in \big[\bar{q}, \frac{p^N}{p^N+(1-p)^N}\big)$, we want to show that $V^{\beta}_{G_0} \geq V^{\alpha}_{G_0}$. Note that if k doesn't change as q' increases, then all those probabilities won't change, so we are done. Now suppose that k decreases by 1 as because of the increase from $\bar{q}$ to q'. Note that the probabilities won't change if they are associated with groups with $x \leq k-3$ and groups with $x \geq N-k+2$. Define $f(k) = \big(V^{\alpha}_L - V^{\beta}_L\big) \cdot P_L + \big(V^{\alpha}_K - V^{\beta}_K\big) \cdot P_{k-1}$. Relying on the expressions we got from the proof of Theorem 2, we obtain that

$$
\begin{aligned}
& f(k-1) - f(k) - \left(V^{\alpha}_{k-2} - V^{\beta}_{k-2}\right) \cdot P_{k-2} - \left(V^{\alpha}_{N-k+1} - V^{\beta}_{N-k+1}\right) \cdot P_{N-k+1} \\
={}& (q-p)(2p-1) \sum_{\ell=k-1}^{N-k+1} \frac{C^{\ell-1}_{N-1}}{\ell} p^{\ell-1}(1-p)^{N-\ell-1} + \frac{C^{k-2}_{N-1}(2p-1)^2}{N-k+2} \sum_{\ell=k-1}^{N-k+1} p^{N-l-1}(1-p)^{\ell-1} \\
& - (q-p)(2p-1) \sum_{\ell=k}^{N-k} \frac{C^{\ell-1}_{N-1}}{\ell} p^{\ell-1}(1-p)^{N-\ell-1} - \frac{C^{k-1}_{N-1}(2p-1)^2}{N-k+1} \sum_{\ell=k}^{N-k} p^{N-l-1}(1-p)^{\ell-1} \\
<{}& (q-p)(2p-1)\Big(\frac{C^{k-2}_{N-1}}{k-1} p^{k-2}(1-p)^{N-k} + \frac{C^{N-k}_{N-1}}{N-k+1} p^{N-k}(1-p)^{k-2}\Big) \\
& + \frac{C^{k-2}_{N-1}(2p-1)^2}{N-k+2}\Big(p^{N-k}(1-p)^{k-2} + p^{k-2}(1-p)^{N-k}\Big) \\
& - \frac{C^{k-2}_{N-1}(2p-1)}{N-k+2}\Big(p^{N-k+1}(1-p)^{k-2} - p^{k-2}(1-p)^{N-k+1}\Big) \\
={}& (q-p)(2p-1)\Big(\frac{C^{k-2}_{N-1}}{k-1} p^{k-2}(1-p)^{N-k} + \frac{C^{N-k}_{N-1}}{N-k+1} p^{N-k}(1-p)^{k-2}\Big) \\
& - \frac{C^{k-2}_{N-1}(2p-1)}{N-k+2}\Big(p^{N-k}(1-p)^{k-1} - p^{k-1}(1-p)^{N-k}\Big) \\
<{}& 0
\end{aligned}
$$

This implies that when k strictly decreases, the value of $V^{\beta}_{G_0} - V^{\alpha}_{G_0}$ strictly increases. ■

With all previous calculations, we conclude in Theorem 3 the set of all problems under which there is no IE mechanism.

Theorem 3. *There exists no informationally efficient mechanism for any $c > 0$ if and only if problem (p, q, q', N) satisfies*

$$
\begin{aligned}
& \sum_{i=0}^{k-2} \frac{C^{i}_{N-1}\Big((1-p)^i p^{N-i-1} - p^i(1-p)^{N-i-1}\Big)}{N-i} \\
& + \sum_{l=k}^{N-k} \frac{C^{\ell-1}_{N-1}}{\ell}(q-p)p^{\ell-1}(1-p)^{N-\ell-1} + \frac{C^{k-1}_{N-1}}{N-k+1}(2p-1)\sum_{\ell=k}^{N-k} p^{N-\ell-1}(1-p)^{\ell-1} \leq 0
\end{aligned}
$$

where k is determined by q', p, and N as we defined in Section 3.1.1.

To prove Theorem 3, we combine our previous calculations in the proofs of Theorem 2 and Proposition 6. Many of our previous results, including Proposition 1, Proposition 2, Proposition 3, and Proposition 5, can be regarded as corollaries of Theorem 3. However, we follow a natural order of how we obtain the results and how people should consider the problem, and we believe those results are far more important than Theorem 3 for us to understand the intuition and the role of belief discrepancy. Since one can hardly read anything from the cumbersome expression of Theorem 3, we simply leave it here for readers' reference.

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