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DELIBERATION AND ITS EFFECT ON VOTING: NASH BAYESIAN EQUILIBRIUM WITH COMMUNICATION AND ENDOGENOUS INFORMATION ACQUISITION

TESIS PARA OPTAR AL GRADO DE MAGÍSTER EN ECONOMÍA APLICADA

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RESUMEN DE LA TESIS PARA OPTAR AL GRADO DE MAGÍSTER EN ECONOMÍA APLICADA
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We analyze the amount of information acquired by agents in the case where they make their decisions based only in their private beliefs versus the case where they can exchange information. In other words, we model the information acquisition when communication between agents is available. We focus on committees or decision panels that are comprised of a collection of agents sharing a common goal, having a joint task, and possessing the ability to communicate at no cost. We focus in unanimity as a voting rule and show that if communication is available, then agents may have incentives to acquire information only when they share information. Intuitively, we would expect that information sharing decreases the incentives to exert effort and observe a free rider problem. However, our results show that, under fairly conditions, communication creates incentives to acquire information. Our analysis puts in evidence the importance of incorporate communication when information acquisition is analyzed. Also, we discuss extensions on the voting rule and costly communication.

In our model, a committee of experts has to decide on behalf of the public (or an organization) whether to implement a project or to maintain the status quo. Committee members have common preferences. The problem is that the consequences of the project are uncertain. In the first stage, agents acquire costly information and receive a private signal about the state of the world. Then, agents deliberate and vote. The committee reaches a decision in two stages. In the first stage, the communication stage, each member can share his privately held view with the other members. We assume that members simultaneously reveal their views. In the second stage, the voting stage, members cast their votes simultaneously, and votes are aggregated using unanimity as a voting rule.

Our results show that, in the voting stage, agents vote strategically in both cases, when information is shared and when is not. That is, agents may vote against their signal. In the communication stage, we find that agents may not have incentives to communicate their signal, even if communication is costless. Finally, we find that if the number of agents is big enough, then each agents prefers to communicate their signal and acquire information. Contrary to the intuition, we find conditions such that the free rider effect is not observed and communication creates more incentives to acquire information.

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DELIBERACIÓN Y SUS EFECTOS EN LA VOTACIÓN: EQUILIBRIO DE NASH BAYESIANO CON COMUNICACIÓN Y ADQUISICIÓN DE INFORMACIÓN ENDÓGENA

Analizamos la cantidad de información adquirida por los agentes, en el caso donde toman sus decisiones en base a creencias privadas versus el caso donde existe intercambio de información. En otras palabras, modelamos la adquisición de información cuando los agentes tienen la opción de comunicar y deliberar. Nos enfocamos en comités o paneles de decisión compuestos por un grupo de agentes que comparten una meta común, una tarea conjunta, y que poseen la habilidad de comunicarse sin costo. Consideramos la unanimidad como regla de votación y demostramos que si existe la oportunidad de comunicar, entonces los agentes podrían tener incentivos a adquirir información sólo cuando comunican. Intuitivamente, esperaríamos que el compartir información decrezca los incentivos a realizar esfuerzo y observar un efecto free rider. Sin embargo, nuestros resultados muestran que, bajo ciertas condiciones, la comunicación genera incentivos a adquirir información. Nuestro análisis deja en evidencia, la importancia de incorporar comunicación cuando se analiza la adquisición de información. Además, discutimos extensiones sobre la regla de votación y comunicación costosa.

En nuestro modelo, un comité de expertos debe decidir, en representación del público (o una organización), si implementar un proyecto o mantener el status quo. Los miembros del comité tienen preferencias comunes. El problema es que existe incertidumbre acerca de las consecuencias del proyecto. En la primera etapa, los agentes adquieren información costosa y reciben una señal privada acerca del estado del mundo. Luego, los agentes deliberan y votan. El comité alcanza una decisión en dos etapas. En la primera etapa, la etapa de comunicación, cada miembro puede compartir su información privada con los demás. Suponemos que los agentes revelan su señal simultáneamente. En la segunda etapa, la etapa de votación, cada miembro vota simultáneamente, donde los votos son agregados utilizando como regla de votación la unanimidad.

Nuestros resultados muestran que, en la etapa de votación, los agentes votan estratégicamente en ambos casos, cuando la información es compartida y cuando no. Esto es, los agentes votan en contra de su señal. En la etapa de comunicación, encontramos que los agentes pueden no tener incentivos en comunicar su señal, incluso cuando la comunicación no tiene costo. Finalmente, encontramos que si el número de agentes es lo suficientemente grande, entonces cada miembro prefiere comunicar su señal y adquirir información. Contrario a la intuición, encontramos condiciones tales que el efecto free rider no se observa, y la comunicación crea más incentivos a adquirir información.

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Chapter 1

Introduction

1.1 Motivation

We do not live in a silent world, committees and jurors deliberate and exchange information before making a decision. Therefore, collective decision benefits from the possibility of information exchange and discussion before a decision is made. Moreover, compare to individual decision making, decisions taken by a group might be based on more or better information than individual decisions. In the same context, decision making process also requires information acquisition, where agent learn about the state of the world and decrease the uncertainty before reaching a decision. In other words, agents have to educate themselves and learn about which option is better. The present thesis models a collective decision processes involving deliberation and information acquisition under unanimity rule.

We focus on committees or decision panels that are comprised of a collection of agents sharing a common goal, having a joint task, and possessing the ability to communicate at no cost. Decisions in business are made by, management teams, audit committees, and boards of governors. Tenure and promotion decisions in academia and law firms are typically made by committees. Also, important decisions are made by committees. The Federal Open Market Committee (Federal Reserve System) and the Governing Council (European Central Bank) decide on monetary policy. In the European Parliament, there are seventeen committees dealing with internal policies and three committees dealing with external policies. Important national policy decisions are made by the Council of Ministers and not by a single minister. The health care profession makes extensive use of expert consensus panels.

Situations where decision makers need to make effort before reached a decision are common. For example, refereeing process, where an editor requires the opinions of a number of experts who must read the paper (acquire information) in order to give an opinion as to publication. Analogously, in committees which screen applicants to a programme, the committee members must gain information about the applicant's qualifications and likelihood of success in order to evaluate whether to admit her. Finally, in trial juries it is important that jurors pay attention to the evidence in order to make an informed judgement.

In our model, a committee of experts has to decide on behalf of the public (or an organization) whether to implement a project or to maintain the status quo. Committee members have common preferences. The problem is that the consequences of the project are uncertain. We model information acquisition when communication between agents is available. In the fist stage, agents acquire costly information according to some increasing and convex cost function. Then, agents deliberate and vote. The committee reaches a decision in two stages. In the first stage, the communication stage, each member can share his privately held view with the other members. We assume that members simultaneously reveal their views. In the second stage, the voting stage, members cast their votes simultaneously, and votes are aggregated using unanimity as a voting rule.

1.2 Related Literature

One of the first to show the importance of communication on jury models was Coughlan [7]. He extended the Feddersen and Pesendorfer's [11] model, allowing limited communication among jurors and considering a pre-voting stage. He shows that voters reveal their information truthfully if and only if their preferences are sufficiently close and that jurors have no incentives to vote strategically in the final vote. Therefore, when information is shared, all jurors either agree that the defendant is guilty or agree that the defendant is not guilty. This result contradicts, Feddersen and Pesendorfer, that unanimous jury verdicts lead to strategic voting and imply a higher probability of convicting the innocent than simple majority rule. Gerardi and Yariv [12], also suggests the importance of incorporate communication in models of collective choice. They analyze a model of jury decision making in which jurors deliberate before casting their votes and show that deliberations render these equivalent with respect to the sequential equilibrium outcomes they generate.

Other important contribution is Austen-Smith and Feddersen [2]. They consider a committee of three agents who need to choose one of two alternatives. Each agent has private information on two dimensions: perfect information concerning her preferences and noisy information concerning the state of the world. They model deliberations as a one round process in which all agents simultaneously send public messages. They find that majority rule induces more information sharing and fewer decision making errors than unanimity. An extension is Austen-Smith and Feddersen [3] look at a similar environment in which any number of agents can publicly send arbitrary messages before casting their votes. They provide conditions under which unanimity cannot induce full revelation of private information in equilibria comprised of weakly undominated strategies. Furthermore, if full revelation is possible under unanimity, then it is possible under any other rule.

In a similar way, there has been some experimental work on voting with communication. Guarnaschelli, McKelvey, and Palfrey [15] constructed an experiment replicating Coughlan's [7] setup. They present experimental results on groups facing a decision problem analogous to that faced by a jury, and find evidence of strategic voting under the unanimity rule where a large fraction of subjects vote for a decision analogous to conviction even when their private information indicates a state analogous to innocence. In conclusion, they noted that during deliberations, voters tend to expose their private information but not to the full extent as predicted by Coughlan's [7] results. Recently, Goeree and Yariv [14] conducted an array of experiments testing for the effects of free form communication on jury outcomes. Their results show that when deliberation is prohibited, different institutions generate significantly different outcomes, tracking the theoretical comparative statics. Deliberation, however, significantly diminishes institutional differences and uniformly improves efficiency. Furthermore, communication protocols exhibit an array of stable attributes: messages are public, consistently reveal private information, provide a good predictor for ultimate group choices, and follow particular (endogenous)sequencing.

There is another literature related with decision making process that considers information acquisition where communication between agents is not available. According to the 'rationally ignorance' hypothesis, in large elections voters will not have an incentive to acquire political information before voting because each agent has small probability of affecting the outcome. In Down's [9] words:

> *If all others express their true views, he [the voter] gets the benefit of a well informed electorate no matter how well informed he is; if they are badly informed, he cannot produce those benefits himself. Therefore, as in all cases of individual benefits, the individual is motivated to shirk his share of the costs: he refuses to get enough information to discover his true views. Since all men do this, the election does not reflect the true consent of the governed.*

Martinelli [19], in agreement with Down's rational ignorance hypothesis, finds that individual investment in political information declines to zero as the numbers of voters increases. However, if the marginal cost of information is near zero for nearly irrelevant information, there is a sequence of equilibria such that the election outcome is likely to correspond to the interests of the majority for arbitrarily large numbers of voters. Thus, 'rationally ignorant' voters are consistent with a well informed electorate. In the same line, Persico [21] analyses the design of voting mechanism, where the problem is to choose two parameters which determine the incentive to acquire information and the efficiency with which information is aggregated. The first parameter is the number of committee members and the second is the voting rule. Persico finds that a voting rule that requires unanimity to upset the status quo can be optimal only if the information available to each committee member is sufficiently accurate. Intuitively, each agent makes her decision conditional on the pivotal probability, where members are pivotal when all other members vote to switch from the status quo. If the individual information is noisy, committee members probably will have different perceptions about the best policy and the pivotal probability decreases. Then, if information is costly and must be acquired before the voting stage, committee members will not acquire it. In conclusion, committee members may not invest in information because they expect that their vote will not influence the final decision. Related with the information acquisition, Triossi [24] proves that contrary to the most optimistic positions about direct democracy, majoritarian elections can fail to aggregate information, when voters have heterogeneous skills. Informational inefficiencies can be partially corrected by improving the skills of the electorate as the population increase or by limiting participation to most competent citizens. Results are consistent with Rousseau view that an educated citizenry is necessary for a well functioning democracy.

Our results show that, in the voting stage, when information is not shared agents vote strategically. Accorging to Feddersen and Pesendorfer's [11], this increases the provability of taking the wrong decision. On the contrary, as in Coughlan [7], if communication between agents is available, then all agents will vote in the same direction.

In the communication stage, we find that agent may have incentives to deviate and communicate their signal. Moreover, as communication is costless agents have incentive to deviate and communicate their signal. However, we also show that in particular cases, agents may not have incentives in communicate their signal. As in Coughlan [7], we find that agents share their information truthfully because they have common preferences.

Finally, in the effort decision stage, we find that if n is big enough, then each agents prefers to communicate their signal and acquire information. Contrary to the intuition, we do not find a free rider problem and communication creates more incentives to acquire information. This result is contrary to Mukhopadhaya [20] who finds a free rider problem if the number of jurors increases. Our results puts in evidence the importance of incorporate communication when information acquisition is analyze.

Chapter 2

Model

2.1 Description and Assumptions

Consider a committee with $n \geq 3$ members who have to decide, on behalf of the public (or an organization), whether to implement a project or to reject it and maintain the status quo. The project's payoff depends on a fixed parameter p and a stochastic term $\mu = \{-h, h\}$. There are two possible states of the world: the project is a success or is a failure. We denote by G (Good) the state of the world in which the project is successful and by B (Bad) the state in which the project fails. Each state has equal prior probability.

Agents have identical preferences over decisions and states. By normalization, if the project is rejected each agent receives zero. If the project is implemented and the state of the world is G, each agent receives $p + h$. On the contrary, if the project is implemented and the state of the world is B each agent receives $p - h$. Moreover, we assume i) $p < 0$ to capture the idea that without information the status quo is prefer and ii) $p + h > 0$ implying that the decision will depend on the value of the stochastic term.

At the beginning of the game, agents simultaneously acquire information $\widehat{e}_i \in [0, 1]$. Information is costly, denoted by $C(\widehat{e}_i)$. We assume that $C(0) = 0$, $C'(\cdot) > 0$ and $C''(\cdot) > 0$. After the information acquisition, each agent receives a private signal, $s_i = g$ (the 'good signal') or $s_i = b$ (the 'bad signal') about the true state. A signal is fully informative with probability $\widehat{e}_i$. If s_i is informative, then $\mathbb{P}(S = G \mid s_i = g) = 1$ and $\mathbb{P}(S = B \mid s_i = b) = 1$. A signal is uninformative with probability $1 - \widehat{e}_i$. An uninformative signal does not contain information about the state of the world, then s_i is randomly drawn from $\{b, g\}$ with $\mathbb{P}(b) = \frac{1}{2}$.

Deliberation takes place in two stages. In the first stage, the communication stage, each agent i can communicate her private signal. In the second stage, the voting stage, agents vote for N or Y and no abstentions are allow. We assume that signals are sent simultaneously, and that votes are cast simultaneously. As a voting rule, we consider unanimity.

2.2 Timing

- Nature randomly chooses $S \in \{B, G\}$ with $\mathbb{P}(B) = \frac{1}{2}$.
- Each player i chooses $\widehat{e}_i \in [0, 1]$.
- Each player i observes $s_i \in \{b, g\}$ such that:

$$\mathbb{P}(s_i = g | S = G) = \mathbb{P}(s_i = b | S = B) = \frac{1 + \widehat{e}_i}{2}$$

$$\mathbb{P}(s_i = b | S = G) = \mathbb{P}(s_i = g | S = B) = \frac{1 - \widehat{e}_i}{2}$$

- Each player chooses between communicating (C) or not communicating (NC) her private signal .
- Each player i votes for N or Y.

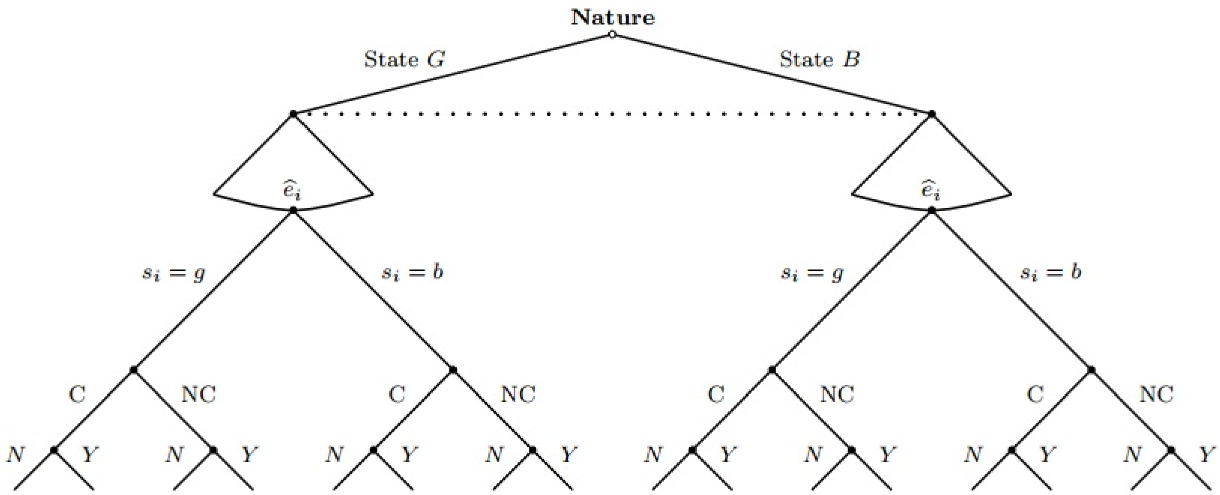

Figure 1. Timing of the game

2.3 Strategy Profile and Equilibrium

We focus on symmetric strategy profiles and symmetric equilibriums, where agents with the same information will choose the same strategy. The amount of information acquired for each agent i is denoted by $\widehat{e} \in [0, 1]$. As an analogous interpretation, let us say that committee members can exert effort and learn about the state of the world, then each agent receives a private signal with certain level of precision that depends on the effort. As in Martinelli [19], each agent makes her effort decision conditional on being pivotal.

The communication decision for each agent i is described by $\phi_s : (0,1) \to \{0,1\}$, where $\phi_s = 1$ represents the fact that each agent communicates her signal $s \in \{b, g\}$ given the effort decision $\widehat{e}$. Let us say that we have *Full Disclosure* when all agents communicate both signals and *Full Non-Disclosure* when all agents conceal both signals. A *Partial Disclosure-g* is when each agent communicates only the 'good signal' and *Partial Disclosure-b* is when each agent communicates only the 'bad signal'. In this stage, we find the conditions under which each case is a symmetric Nash Equilibrium. As in Coughlan [7], this stage can be interpreted as a pre-voting stage, where agents may share information before voting.

The voting behavior for each agent i is described by a strategy mapping $\sigma : (0,1) \times \{0,...,n\} \times \{0,...,n\} \to [0,1]$, with σ being the probability of voting for Y, given the effort made and the number of signals observed. As in Feddersen and Pessendorfer [11], we allow committee members to vote strategically. We say that agents *vote informatively* if each agent votes for Y with probability one after observing the 'good signal' and always votes for N after observing the 'bad signal', and *vote strategically* if they vote for Y with positive probability after observing the 'bad signal'.

An equilibrium is a triple $(\widehat{e}, \phi_s, \sigma)$. We say that agents acquire information or exert effort if $\widehat{e} > 0$. An equilibrium is a *Full Disclosure Equilibrium* if agents communicate both signals, and is a *Full Non-Disclosure Equilibrium* if agents conceal both signals. In the same way, an equilibrium is a *Partially Disclosure Equilibrium* if agents communicate at least one signal.

We conclude this section with a note on equilibria. As the signals become common knowledge in the communication stage before members vote we use subgame perfection. We focus on equilibria in which agents make all their decision conditional on being pivotal.

Chapter 3

Results

3.1 Voting Stage

In this stage, we characterize the voting strategies that are symmetric Nash Equilibriums under each possible communication case. In other word, we define the voting equilibriums under *Full Non-Disclosure*, *Partially Disclosure* and *Full Disclosure*. It is important to note, that all voting behaviors will depend on the level of effort exert by agents. We assume rational agents, then each committee member makes her voting decision conditional on being pivotal. Also, we focus in equilibriums where the project is implemented with strictly positive probability.

First we analyze the voting decision under *Full Non-Disclosure* where all agents conceal information about their signal, then each agent votes conditional on her private information and conditional on the pivotal probability. As in Feddersen and Pesendorfer [11], we allow agents to vote strategically, where σ_g and σ_b represent the probability that each agent votes for Y conditional on receiving the 'good signal' and the 'bad signal' respectively. Let γ_S represents the probability that each agent votes for Y in state $S \in \{B, G\}$, then:

$$\gamma_G = \sigma_g \left(\frac{1 + \widehat{e}}{2} \right) + \sigma_b \left(\frac{1 - \widehat{e}}{2} \right)$$

$$\gamma_B = \sigma_g \left(\frac{1 - \widehat{e}}{2} \right) + \sigma_b \left(\frac{1 + \widehat{e}}{2} \right)$$

Under unanimity rule, for any symmetric strategy profile and for any given agent, we define $\mathbb{P}(piv|S)$ as the probability that $n-1$ other agents vote for Y in state $S \in \{B, G\}$.

The probability that each committee member is pivotal conditional on the state is:

$$\mathbb{P}(piv|G) = \left[\sigma_g\left(\frac{1+\widehat{e}}{2}\right) + \sigma_b\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}$$

$$\mathbb{P}(piv|B) = \left[\sigma_g\left(\frac{1-\widehat{e}}{2}\right) + \sigma_b\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}$$

The pivotal probability in state S is strictly decreasing in the number of agents when $0 < \gamma_S < 1$. As n increases, the probability that one vote change the final outcome decreases. Moreover, as n goes to infinity, the pivotal probability in state S goes to zero.

The probability that one vote change the outcome also depends on the probability that the signal received is correct given the state. If $\sigma_g > \sigma_b$, then $\mathbb{P}(piv|G)$ is increasing in $\widehat{e}$ and $\mathbb{P}(piv|B)$ is decreasing in $\widehat{e}$. Intuitively, if the precision over the signal increases, in state G more agents will receive the 'good signal' and the pivotal probability increases. On the contrary, in state B more agents will receive the 'bad signal' and the pivotal probability decreases.

Under *Full Non-Disclosure*, we characterize the symmetric Nash Equilibriums where the project is implemented with strictly positive probability. Let e_n represent the minimum level of effort needed to vote for Y after observing the 'good signal'. Since agents vote conditional on being pivotal, then this is the minimum level of effort needed to vote for Y after observing n 'good signals'. And e_{n-1} represent the maximum level of effort needed to vote for N after observing the 'bad signal' or $n-1$ 'good signals'. We find that agents *vote informatively* if $e_{n-1} > \widehat{e} \geq e_n$ and *vote strategically* if $\widehat{e} \geq e_{n-1}$.

Proposition 1. ***Voting Equilibriums under Full Non-Disclosure***
Suppose $\widehat{e} \in (0,1)$ and that all agents conceal their signal, then under unanimity rule the symmetric Nash Equilibriums where the project is implemented with strictly positive probability are:

$$(\sigma_g^*, \sigma_b^*) = \begin{cases} (1,0) & \text{if } e_{n-1} > \widehat{e} \geq e_n \\ (1,\beta_1) & \text{if } \widehat{e} \geq e_{n-1} \end{cases}$$

where e_n and e_{n-1} are decreasing in p, h and n; and β_1 is increasing in p, h and n.

Proof. See Appendix. □

Note that vote always for N is also a symmetric Nash Equilibrium in the voting stage. Since the pivotal probability is zero, there is no incentive to deviate.

According to Proposition 1, the project is rejected if the effort is not high enough. Even if all agents have received the 'good signal', all agents prefer to maintain the status quo because there is not sufficient information that supports implementation and the expected benefit received from the project is negative. Then, for $e_n > \widehat{e}$, each agent votes for N independent of the signal received. This is intuitive, since $p < 0$.

Agents *vote informatively* when $e_{n-1} > \widehat{e} \geq e_n$. If agent i receives the 'good signal' and is pivotal, she will vote for Y with probability one because the precision over the signal is sufficiently high such that the expected benefit from making the right decision in state G is higher than the expected cost of making the wrong decision in state B. On the contrary, if agent i receives the 'bad signal' and is pivotal, she will not be willing to implement the project because the expected cost of making the wrong decision in state B is greater than the expected benefit from making the right decision in state G.

Finally, we have the case where each agent *votes strategically*. Agent i will vote for Y with strictly positive probability after observing the 'bad signal' because the precision over the signal is high enough such that the expected benefit from making the right decision in state G is equal to the expected cost of making the wrong decision in state $S = B$.

The mixed strategy β_1 is increasing in p, h and n. The pivotal scenario implies that all other agents have received the 'good signal', then if n increases more agents receive the 'good signal' in state G and agent i will be willing to vote for Y with a higher probability. If p increases, the cost from making the wrong decision in state B decreases and the benefit from making the right decision in state G increases, then agent i will be more willing to vote for Y after observing the 'bad signal' and β_1 increases. If h increases, the expected benefit from making the right decision in state G increases more than the expected cost from making the wrong decision in state B, then β_1 increases.

The minimum and maximum amount of effort required to *vote informatively* are decreasing in n. This result is intuitive. If n increases, more agents have received the 'good signal' in the pivotal scenario, then after observing the 'good signal', she will be willing to vote for Y for a smaller precision over the signal. On the contrary, if agent i observes the 'bad signal', she will vote N if and only if the precision over the signal is small enough since all other agents have received the 'good signal'.

Moreover, the minimum and maximum amount of effort required to *vote informatively* are also decreasing in p and h. If p increases, the benefit from making the right decision in state G increases and the cost from making the wrong decision in state B decreases. Since agent i has more incentives to implement the project, she will vote for Y for smaller levels of precision over the signal. In the other hand, if the stochastic term h increases, the benefit from making the right decision in state G and the cost from making the wrong decision in state B both increases. However, the expect utility received from implement the project in state G increases more than the expected disutility from implement the project in state B.

If agent i receives the 'good signal', she votes for Y conditional on a smaller level of precision and if agent i receives the 'bad signal', she votes for N conditional on a smaller level of precision over the signal.

In the next section we analyze the communication decision, then we need to characterize the voting rule if agent i deviates from the symmetric conceal information strategy. Since agent i will vote according to her private information, let σ_g and σ_b represent the probability that agent i votes for Y after observing the 'good signal' and the 'bad signal' respectively. Now, suppose agent i receives and communicates her signal, then all other agents but i will vote according to her private signal and agent i's signal. Let σ_{gg} and σ_{gb} represent the probability that all other agents but i votes for Y after observing agent i's 'good signal' and their private 'good signal' and 'bad signal' respectively. And, let σ_{bg} and σ_{bb} represent the probability of voting for Y after observing agent i's 'bad signal' and their private 'good signal' and 'bad signal' respectively.

In this case, the probability that each agent votes for Y in state S and the probability that agents are pivotal in state S, both change from the previous definition. For example, suppose agent i has received the 'good signal' and communicates it, then the probability that each agent $j \neq i$ votes for Y in state S is:

$$\gamma_G^j = \sigma_{gg}\left(\frac{1+\widehat{e}}{2}\right) + \sigma_{gb}\left(\frac{1-\widehat{e}}{2}\right)$$

$$\gamma_B^j = \sigma_{gg}\left(\frac{1-\widehat{e}}{2}\right) + \sigma_{gb}\left(\frac{1+\widehat{e}}{2}\right)$$

Under unanimity rule, for any symmetric strategy profile and for any given voter, we define $\mathbb{P}(piv_j|S)$ as the probability that agent $j \neq i$ is pivotal in state S is:

$$\mathbb{P}(piv_j|G) = \sigma_g\left[\sigma_{gg}\left(\frac{1+\widehat{e}}{2}\right) + \sigma_{gb}\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-2}$$

$$\mathbb{P}(piv_j|B) = \sigma_g\left[\sigma_{gg}\left(\frac{1-\widehat{e}}{2}\right) + \sigma_{gb}\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-2}$$

The probability that agent i is pivotal in state S is:

$$\mathbb{P}(piv_i|G) = \left[\sigma_{gg}\left(\frac{1+\widehat{e}}{2}\right) + \sigma_{gb}\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}$$

$$\mathbb{P}(piv_i|B) = \left[\sigma_{gg}\left(\frac{1-\widehat{e}}{2}\right) + \sigma_{bb}\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}$$

Note that agent i can vote for N or Y after observing the 'good signal' or the 'bad signal' . If she votes for N, then the project is not implemented and all other agents are never pivotal. We focus in voting equilibriums where the project is implement with strictly positive probability, then we analyze the case where σ_g and σ_b are strictly positive. Formally:

Proposition 2. ***Voting Equilibriums if one agent deviates from Full Non-Disclosure*** *Suppose $\widehat{e} \in (0,1)$ and that all agents but i conceal information. If agent i receives the 'good signal' and communicates it, then under unanimity rule the symmetric Nash Equilibriums where the project is implemented with strictly positive probability are:*

$$(\sigma_g^*, \sigma_{gg}^*, \sigma_{gb}^*) = \begin{cases} (1,1,0) & \text{if } e_{n-1} > \widehat{e} \geq e_n \\ (1,1,\beta_2) & \text{if } \widehat{e} \geq e_{n-1} \end{cases}$$

where β_2 is increasing in p, h, n and $\widehat{e}$.
On the contrary, if agent i receives the 'bad signal' and communicates it, then under unanimity rule the symmetric Nash Equilibriums where the project is implemented with strictly positive probability are:

$$(\sigma_b^*, \sigma_{bg}^*, \sigma_{bb}^*) = \begin{cases} (1,1,0) & \text{if } e_{n-2} > \widehat{e} \geq e_{n-1} \\ (1,1,\beta_3) & \text{if } \widehat{e} \geq e_{n-2} \end{cases}$$

where e_{n-2} is decreasing in p, h and n; and β_3 is increasing in p, h and n.

Proof. See Appendix. □

In all the symmetric Nash Equilibriums where the project is implemented with strictly positive probability, after communicating the 'good signal' or the 'bad signal', agent i delegates her voting decision and always votes for Y with probability one.

The fact that agent i communicates her signal changes the mixed voting strategy after observing the 'bad signal'. Moreover, $\beta_2 > \beta_1$ and $\beta_1 > \beta_3$. The intuition behind this results is as follows. If agent i observes and communicates the 'good signal' and agent j observes the 'bad signal', this information cancels out with agent i's signal, and agent j will be willing to vote for Y with a higher probability. On the contrary, if agent i receives the 'bad signal' and communicates it, then all other agents will be willing to vote for Y with a smaller probability after observing the 'bad signal' because there is more evidence against implementation.

Communication also changes the boundaries needed to *vote informatively* when agent i receives the 'bad signal'. If agent i receives the 'bad signal' and reveals it, then all agents have information against implementation. Then, when agent j receives the 'good signal', she will be willing to vote for Y if the effort is equal or higher than e_{n-1}, since only $n-1$ agents receive the 'good signal' when she is pivotal. And, if agent j receives the 'bad signal', she will vote for N for higher amounts of effort because the evidence against implementation is greater.

On the contrary, the boundaries needed to *vote informatively* do not change if agent i receives and communicates the 'good signal'. This is intuitive. Since agent j is pivotal when all other agents have received the 'good signal', the expected benefit from making the right decision in state G and the expected cost from making the wrong decision in state B are the same with and without communication.

Finally, we analyze the cases where all agents communicate at least one signal, then each agent votes conditionally on the pivotal probability. We characterize the voting equilibriums under *Full Disclosure*, *Partially Disclosure-g* and *Partially Disclosure-b* cases. Our results show that the voting decision depends on the amount of effort and the total number of signals observed. Let N_g represent the number of 'good signals' observed by each agent and e_{N_g} the minimum effort such that each agent will be willing to vote for Y after observing N_g 'good signals'.

Proposition 3. ***Voting Equilibriums under Full Disclosure and Partially Disclosure***
Suppose n odd and $\widehat{e} \in (0,1)$. Consider the following cases: I) all agents communicate their signal, II) all agents communicate only the 'good signal', and III) all agents communicate only the 'bad signal'. Then, under any voting rule, the symmetric Nash Equilibrium where the project is implemented with strictly positive probability is $\sigma^* = 1$ if $N_g \geq \frac{n-1}{2} + 1$ and $\widehat{e} > e_{N_g}$, where e_{N_g} is decreasing in p, h and N_g.

Proof. See Appendix. □

According to Proposition 3, agent i will vote for Y if two conditions are met. First, there is a necessary but not sufficient condition over the number of signals observed. Secondly, we have a condition related to the amount of effort.

As in Coughlan [7], if agents share information in the pre voting stage or communication stage, then during the voting stage all agents will either agree to implement the project or agree to maintain the status quo.

It is important to note that the voting rule is equivalent in cases I), II) and III). The intuition is as follows. Suppose n odd and consider the case where all agents communicate the 'good signal' and conceal the 'bad signal', then agent i will vote for Y if she observes at least $\frac{n-1}{2} + 1$ 'good signals' and $\widehat{e} > e_{N_g}$. Now, consider the case where all agents communicate the ‘bad signal’ and conceal the ‘good signal’, then agent i will vote for Y if she observes no more than $\frac{n-1}{2}$ ‘bad signals’ and $\widehat{e} > e_{N_b}$. In the later case, if agent i observes an ‘empty signal’ from agent j, she believes that agent j has received the ‘good signal’ and will vote for Y if she observes at least $\frac{n-1}{2}+1$ ‘empty signals’, which is equivalent to say that she has observed at least $\frac{n-1}{2}+1$ ‘good signals’. Then, without loss of generality, we define the voting rule in each case conditional on the number of ‘good signals’ observed.

The minimum level of precision required to vote for Y is decreasing in N_g. This is intuitive. If the number of ‘good signals’ observed increases, there is more evidence that supports implementation. Then, agent i will be willing to vote for Y for a smaller amounts of information.

In summary, if agents communicate their signal, then each agent will vote for Y if they have observed at least half plus one of good signals in the communication stage. This implicates that given any voting rule, if communication is available between agents, they will behave as under majority rule.

3.2 Communication Stage

In this stage we analyze if *Full Non-Disclosure*, *Partially Disclosure* and *Full Disclosure* are or not symmetric Nash Equilibrium given the voting rules found in the previous section. Also, we define the condition over which the equilibriums exist. It is important to note that a strategic agent will condition her decision on the voting stage; that is, her signal can change the final outcome during the voting stage.

First we analyze if *Full Non-Disclosure* is a symmetric Nash Equilibrium. Our results show, that agents have no incentive to deviate from the conceal information strategy after observing the ‘good signal’ and have incentives to deviate and communicate the ‘bad signal’.

Proposition 4. ***Full Non-Disclosure***
Consider the symmetric voting equilibriums defined in Proposition 1 and Proposition 2. Suppose $\widehat{e} \in (0,1)$, then Full Non-Disclosure is always a symmetric Nash Equilibrium in the communication stage for $e_{n-1} > \widehat{e}$.

Proof. See Appendix. □

Agents have no incentive to deviate from the conceal information strategy after observing the ‘good signal’. This is intuitive. Suppose agent i has received the ‘good signal’ and all other agents conceal information. When $e_n > \widehat{e}$, for any communication decision, there is no evidence that supports implementation and the project is rejected, then agent i is indifferent between communicating or concealing her signal. When $e_{n-1} > \widehat{e} \geq e_n$, each agent *votes informatively* and communication does not change the expected utility given the pivotal probability, then agent i does not communicate the 'good signal'. The interesting case is when $\widehat{e} > e_{n-1}$, where agents votes for Y with a positive probability after observing the 'bad signal'. The expected utility for agent i when she chooses $\phi_g = 0$ is always greater than the expected utility when she chooses $\phi_g = 1$. The intuition is as follows. If agent i deviates and communicates her signal, since $\beta_2 > \beta_1$, the pivotal probability increases in both states and the expected benefit from making the right decision in state G decreases and the expected cost from making the wrong decision in state B increases. Then, agent i conceals the 'good signal'.

On the contrary, agent i has incentives to deviate and communicate the 'bad signal'. Suppose agent i has received the 'bad signal' and all other agents conceal information. When $e_n > \widehat{e}$, for $\phi_g = 1$ and $\phi_g = 0$, there is no evidence that supports implementation and the project is rejected, then agent i is indifferent between communicating or concealing her signal. When $e_{n-1} > \widehat{e} \geq e_n$, for $\phi_g = 1$ and $\phi_g = 0$, the project is not implemented and agent i is indifferent between communicating or concealing her signal. Now, suppose $e_{n-2} > \widehat{e} \geq e_{n-1}$. If agent i does not communicate her signal, she will vote for Y according to the mixed strategy profile β_1 and will receive an expected payoff equal to zero; and if she communicates her signal, she will vote for Y and will delegate the final decision to other agents and her expected utility will be strictly positive. Then agent i will conceal information. Finally, consider $\widehat{e} \geq e_{n-2}$, where the only difference with the previous case is that all other agents who received the 'bad signal' will vote for Y with strictly positive probability. Then agent i will conceal information.

Now we characterize *Full Disclosure*, *Partial Disclosure-g* and *Partial Disclosure-b*. A rational agent will make her communication decision conditional on the pivotal probability in the voting stage, where agent i might be decisive in the number of signals needed to vote for Y given a fixed amount of effort. Without loss of generality, we characterize the symmetric Nash Equilibriums conditional on the number of 'good signals', because each agent i can infer the number of 'good signals' from the number of 'bad signals'.

Proposition 5. ***Partially Disclosure and Full Disclosure***
Consider the symmetric voting equilibriums defined in Proposition 3. Suppose $\widehat{e} \in (0, 1)$, *then Full Disclosure, Partial Disclosure-g and Partial Disclosure-b are symmetric Nash Equilibriums in the communication stage.*

Proof. See Appendix. □

This result is intuitive. If communication is costless then agents always have incentives to communicate their signal and aggregate information. An interesting case is when communication is costly. We will discuss this result as an extension of the model in the next chapter.

3.3 Information Acquisition Stage

In the following section, we characterize the information acquisition or effort decision given the results found in the previous two sections. Each agent i makes the effort decision conditional on being pivotal. As in Martinelli [19], we find that in large elections $C'(0) = 0$ is a necessary and sufficient condition for the existence of an equilibrium with information acquisition. Moreover, in our model, we can consider that even if the expected benefit received from the implementation of the project is close to zero, agents have incentives to acquire information. Also, our results how that if n is sufficiently high, then agents will exert effort only if communication is available.

As an abuse of notation, let us represent the effort decision for agent i as e_i. Let $G(e_i)$ represent the expect utility received for each agent i under *Full Non-Disclosure*. According to Preposition 4, *Full Non-Disclosure* is a symmetric Nash Equilibrium in the communication stage only for $e_{n-1} > e_i$, then:

$$G(e_i) = \begin{cases} -C(e_i) & \text{if } e_n > e_i \\ \\ \frac{1}{2}(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{n-1}\left(\frac{1+e_i}{2}\right) + \frac{1}{2}(p-h)\left(\frac{1-\widehat{e}}{2}\right)^{n-1}\left(\frac{1-e_i}{2}\right) - C(e_i) & \text{if } e_{n-1} > e_i \geq e_n \end{cases}$$

In this case, agent i is pivotal when $n-1$ other agents vote for Y, where each agent votes for Y with probability one after observing the 'good signal' and always votes for N after observing the 'bad signal'. Since agents do not communicate their signal, there is not pivotal probability in the communication stage.

According to Preposition 5, *Full Disclosure*, *Partially Disclosure-g* and *Partially Disclosure-b* are always Nash Equilibriums. Suppose n odd and let $H(e_i)$ represent the expect utility that each agent i, which is equivalent under the three cases, then:

$$H(e_i) = \begin{cases} -C(e_i) & \text{if } e_n > e_i \\ \frac{1}{2}\frac{(n-1)!}{\left(\frac{n-1}{2}\right)!\left(\frac{n-1}{2}\right)!}(p+e_ih)\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}} - C(e_i) & \text{if } e_i \geq e_n \end{cases}$$

Note that, each agent i is pivotal when $\frac{n-1}{2}$ other agents receive the 'good signal' in the communication stage. Since all agents vote for Y or N in the voting stage after communicating their signal, we consider the pivotal case in the communication stage.

As in Martinelli [19], the following Proposition states states that $C'(0) = 0$ is a necessary and sufficient condition for the existence of an equilibrium with information acquisition, and characterizes this equilibrium.

Proposition 6. ***Information acquisition***
Consider Proposition 4 and 5, then:

- *If $C'(0) = 0$, there is an equilibrium with information acquisition and it is unique, where e_i^* solves:*
  - *For Full Non-Disclosure:*

$$\frac{1}{4}(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{n-1} - \frac{1}{4}(p-h)\left(\frac{1-\widehat{e}}{2}\right)^{n-1} = C'(e_i) \tag{3.1}$$

  - *For Full Disclosure and Partially Disclosure:*

$$\frac{1}{2}\binom{n-1}{\frac{n-1}{2}} h \left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}} \left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}} = C'(e_i) \tag{3.2}$$

- *If $C'(0) > 0$, there is some $\overline{n}$ such that for every $n \geq \overline{n}$ (holding the other parameters of the model constant) there is no equilibrium with information acquisition.*

Proof. See Appendix. □

Our results show that agents will acquire information if $C'(0) = 0$. Intuitively, if the marginal cost of acquire information is zero in $e_i = 0$, then agents have incentives to acquire a strictly positive amount of information and the solution is not biding. Even if n goes to infinity or the expected benefit received from the implementation of the project is close to zero, agents will acquire information according to the FOCs (3.1) and (A.6).

Also, we find that agents may no have incentive in acquire information if $C'(0) > 0$. In this case, if the expected benefit received from implement the project is close to zero and the marginal cost is strictly positive for any level of effort, then agent will no have incentives to acquire information. Moreover, if n increases then agents will not acquire information, since the expect benefit from implementation decreases with the number of agents.

Finally, we find that there is an equilibrium where agents communicate their signal and acquire information. Even under unanimity rule, agents behave and acquire information according to a majority rule.

Proposition 7. *Suppose $C'(0) > 0$ and h high enough, then there is some $\underline{n}$ such that for every $n \geq \underline{n}$ (holding the other parameters of the model constant) there is an equilibrium where agents communicate and acquire information.*

Proof. See Appendix. □

Intuitively, if n increases the expected benefit received under *Full Non-Disclosure* converges to zero faster than the expected benefit received under *Full Disclosure*, *Partially Disclosure-g* and *Partially Disclosure-b*. We can conclude that, if communication is available between agents, then they will acquire information even if n is big.

3.4 Example

Consider $n = 11$, $p = -0.5$, $h = 20$ and $C(e_i) = (e_i + 0.001)^2$. Under *Full Non-Disclosure* the expected utility is given by:

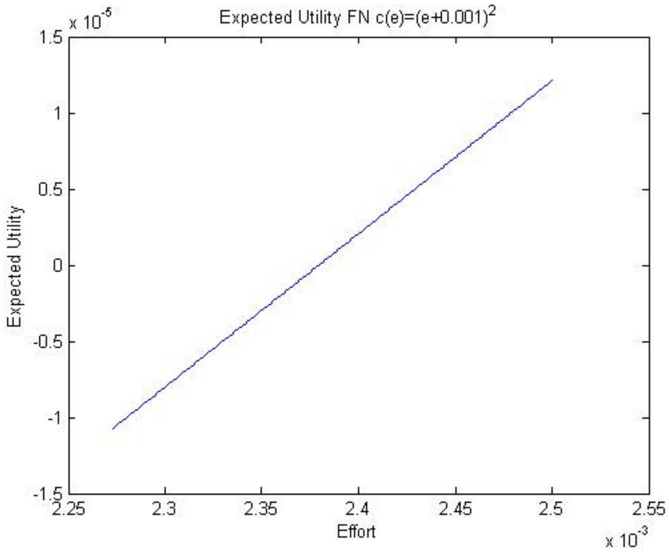

Figure 1. *Full Non-Disclosure* Expected Utility

On the other hand, under *Full Disclosure*, *Partially Disclosure-g* and *Partially Disclosure-b* the expected utility is given by:

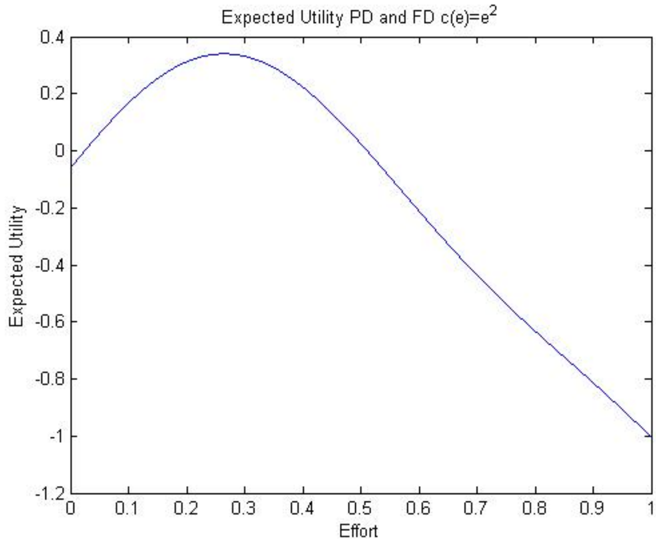

Figure 2. *FD*, *PD-g* and *PD-b* Expected Utility

It is easy to see that agents prefer communicate their signal and acquire information.

Chapter 4

Conclusions

Our main conclusion is that communication affects the amount of information acquired. Moreover, if n is big, agents may have incentives to acquire information only when communication is available. Intuitively, we would expect that information sharing decrease the incentives to exert effort and observe a free rider problem. However, our results show that communication creates incentives to acquire information when n is high enough. Our analysis puts in evidence the importance of incorporate communication when information acquisition is analyze.

According to the literature, we find that agents vote strategically if deliberation is not consider, and do not vote strategically if communication is incorporated. Moreover, as we consider a pre voting stage, agents share information and vote for the same option during the voting stage. Also, our results show that agents communicate their signal if communication is costless.

As interesting extension is consider any supermajority rule and analyze information acquisition when communication is available. Intuitively, we expect the same result. Since the expected benefit received under any supermajority should converge to zero faster than majority rule. Now, we analyze the communication's equilibrium if sharing information is costly. We find that the existence of equilibriums change and depends on the communication's cost, where more educated agent have more incentives in deliberate.

4.1 Extension

As an extension, consider costly communication where agents can communicate the signal $s \in \{b, g\}$ with a cost $\varepsilon > 0$. We find that *Full Non-Disclosure* may be an equilibrium in the communication stage for higher levels of effort. Formally, let $\mathbb{E}U_b^{FN}$ represents each agent's expected utility when she communicates the 'bad signal', then:

Corollary 1. ***Full Non-Disclosure***
Consider the symmetric voting equilibriums defined in Proposition 1 and Proposition 2. Suppose $\widehat{e} \in (0,1)$ *and* $\varepsilon > 0$*, then:*

1) *For* $e_{n-1} > \widehat{e}$*, Full Non-Disclosure is always a symmetric Nash Equilibrium.*

2) *For* $\widehat{e} \geq e_{n-1}$*, Full Non-Disclosure is a symmetric Nash Equilibrium in the communication stage , if* $\varepsilon > \mathbb{E}U_b^{FN}$*, where:*

$$\mathbb{E}U_b^{FN} = \begin{cases} \dfrac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{n-1}\left(\frac{1-\widehat{e}}{2}\right)+(p-h)\left(\frac{1-\widehat{e}}{2}\right)^{n-1}\left(\frac{1+\widehat{e}}{2}\right)}{\left(\frac{1+\widehat{e}}{2}\right)^{n-1}\left(\frac{1-\widehat{e}}{2}\right)+\left(\frac{1-\widehat{e}}{2}\right)^{n-1}\left(\frac{1+\widehat{e}}{2}\right)} & \text{if } e_{n-2} > \widehat{e} \geq e_{n-1} \\ \\ \dfrac{(p+h)\left[\left(\frac{1+\widehat{e}}{2}\right)+\beta_3\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1-\widehat{e}}{2}\right)+(p-h)\left[\left(\frac{1-\widehat{e}}{2}\right)+\beta_3\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1+\widehat{e}}{2}\right)}{\left[\left(\frac{1+\widehat{e}}{2}\right)+\beta_3\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1-\widehat{e}}{2}\right)+\left[\left(\frac{1-\widehat{e}}{2}\right)+\beta_3\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1+\widehat{e}}{2}\right)} & \text{if } \widehat{e} \geq e_{n-2} \end{cases}$$

Proof. Appendix. □

As we find in Proposition 4, even if information is costless, agents have no incentive to deviate from the conceal information strategy after observing the 'good signal'. When communication is costly, agent i may not have incentives to deviate and communicate the 'bad signal'. Suppose agent i has received the 'bad signal' and all other agents conceal information. When $e_n > \widehat{e}$, for $\phi_g = 1$ and $\phi_g = 0$, there is no evidence that supports implementation and the project is rejected, then agent i does not communicate her signal. When $e_{n-1} > \widehat{e} \geq e_n$, for $\phi_g = 1$ and $\phi_g = 0$, the project is not implemented and agent i prefers to conceal information. Now, suppose $e_{n-2} > \widehat{e} \geq e_{n-1}$. If agent i does not communicate her signal, she will vote for Y according to the mixed strategy profile β_1 and will receive an expected payoff equal to zero; and if she communicates her signal, she will vote for Y and will delegate the final decision to all other agents and her expected utility will be strictly positive. Then agent i will conceal information if the communication's cost is higher than the positive expected utility received from implement the project. Finally, consider $\widehat{e} \geq e_{n-2}$, where the only difference with the previous case is that all other agents who received the 'bad signal' will vote for Y with strictly positive probability. Then agent i will conceal information conditional on the communication's cost.

Now, consider *Full Disclosure*, *Partial Disclosure-g* and *Partial Disclosure-b*. Let $\mathbb{E}U_g^{PD}$ represents each agent's expected utility when she communicates the 'good signal' and $\mathbb{E}U_b^{PD}$ represents each agent's expected desutility after concealing the 'bad signal'.

Corollary 2. ***Partially Disclosure and Full Disclosure***
Consider the symmetric voting equilibriums defined in Proposition 3. Suppose n odd, $\widehat{e} \in (0,1)$ and $\varepsilon > 0$, then:

1) *Full Disclosure where agents communicate both signals is not a symmetric Nash Equilibrium in the communication stage.*

2) *For $e_n > \widehat{e}$, Partially Disclosure where agents communicate only the 'good signal' and Partially Disclosure where agents communicate only the 'bad signal' are not symmetric Nash Equilibriums in the communication stage.*

3) *For $\widehat{e} \geq e_n$, Partially Disclosure where agents communicate only the 'good signal' is a symmetric Nash Equilibrium in the communication stage when agents believe that only the 'bad signals' are being concealed and $\mathbb{E}U_g^{PD} \geq \varepsilon$, where:*

$$\mathbb{E}U_g^{PD} = \begin{cases} \dfrac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}}+(p-h)\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}}{\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}}+\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}} & \textit{if } \widehat{e} \geq e_{\frac{n-1}{2}+1} \\[2ex] \dfrac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{N_g}\left(\frac{1-\widehat{e}}{2}\right)^{n-N_g}+(p-h)\left(\frac{1-\widehat{e}}{2}\right)^{N_g}\left(\frac{1+\widehat{e}}{2}\right)^{n-N_g}}{\left(\frac{1+\widehat{e}}{2}\right)^{N_g}\left(\frac{1-\widehat{e}}{2}\right)^{n-N_g}+\left(\frac{1-\widehat{e}}{2}\right)^{N_g}\left(\frac{1+\widehat{e}}{2}\right)^{n-N_g}} & \textit{if } e_{\frac{n-1}{2}+1} > \widehat{e} \geq e_n \\ & \textit{and } e_{N_g-1} \geq \widehat{e} > e_{N_g} \end{cases}$$

4) *For $\widehat{e} > e_n$, Partially Disclosure where agents communicate only the 'bad signal' is a symmetric Nash Equilibrium in the communication stage when agents believe that only the 'good signals' are being concealed and $-\varepsilon \geq \mathbb{E}U_b^{PD}$, where:*

$$\mathbb{E}U_b^{PD} = \begin{cases} \dfrac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}+(p-h)\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}}{\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}+\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}-1}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}} & \textit{if } \widehat{e} \geq e_{\frac{n-1}{2}+1} \\[2ex] \dfrac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{N_g-1}\left(\frac{1-\widehat{e}}{2}\right)^{n+1-N_g}+(p-h)\left(\frac{1-\widehat{e}}{2}\right)^{N_g-1}\left(\frac{1+\widehat{e}}{2}\right)^{n+1-N_g}}{\left(\frac{1+\widehat{e}}{2}\right)^{N_g-1}\left(\frac{1-\widehat{e}}{2}\right)^{n+1-N_g}+\left(\frac{1-\widehat{e}}{2}\right)^{N_g-1}\left(\frac{1+\widehat{e}}{2}\right)^{n+1-N_g}} & \textit{if } e_{\frac{n-1}{2}+1} > \widehat{e} > e_n \\ & \textit{and } e_{N_g-1} \geq \widehat{e} > e_{N_g} \end{cases}$$

Proof. See Appendix. □

Partially Disclosure are symmetric Nash Equilibriums conditional on the communication's cost. Nevertheless, if $e_n > \widehat{e}$, the *Partially Disclosure* are not Nash Equilibriums. This is intuitive. Since agents always vote for N, independent of the number of signals observed, they strictly prefer conceal information.

Consider $\widehat{e} > e_{\frac{n-1}{2}+1}$. In this case, the signal's precision is high enough such that each agent always votes for Y after observing N_g 'good signals' (when $N_g \geq \frac{n-1}{2}+1$), then agent i makes her communication decision conditional on being pivotal in the minimum number of 'good signals' needed to vote for Y. In the *Partially Disclosure-g*, agent i communicates her 'good signal' if the expected utility received after observing $\frac{n-1}{2}+1$ 'good signals' is greater than the communication's cost. The intuition is as follows. Agents believe that only the 'bad signals' are being concealed, then each agent strictly prefers conceal information after observing the 'bad signal'; because under the agent's belief, the project will not be implemented and there is no need to communicate her signal. On the contrary, if agent i receives the 'good signal' and does not communicate it, the project is not implemented under the agent's beliefs, then agent i communicates the 'good signal' conditional on the communication's cost and the expected utility received from implementation. In the *Partially Disclosure-b*, agent i communicates her 'bad signal' if the expected utility received after observing $\frac{n-1}{2}$ 'good signals' is more negative than the communication's cost. Agents believe that only the 'good signals' are being concealed, then each agent strictly prefers conceal information after observing the 'good signal'; because under the agent's belief, the project is implemented and there is no need to communicate her signal. But, if agent i receives the 'bad signal', under agent's belief, the project is implemented and the expected utility received is negative. Then, agent i communicates the 'bad signal' conditional on the communication's cost.

Finally, consider $e_{\frac{n-1}{2}+1} \geq \widehat{e} > e_n$, where agent i is decisive in the number of signals needed to vote for Y given a fixed level of precision over the signal. In this case, agent i makes her communication decision comparing the expected utility received given $N_g - 1$ versus N_g 'good signals'. Nevertheless, when $e_{N_g-1} > \widehat{e} = e_{N_g}$, the expected utility from implementation is zero and agents never communicate, then agents might have incentives to communicate her signal when $e_{N_g} \geq \widehat{e} > e_{N_g}$. In the *Partial Disclosure Equilibrium-g*, agent i communicates her 'good signal' if the expected utility received after observing N_g 'good signals' is greater than the communication's cost. Under agent's beliefs, the project is not implemented after observing $N_g - 1$, then agent i communicates her 'good signal' if the expected utility is high enough. In the *Partial Disclosure Equilibrium-b*, agent i communicates her 'bad signal' if the expected utility received after observing $N_g - 1$ 'good signals' is more negative than the communication's cost. In this case, if agent i does not communicate her signal, she receives a negative expected utility, then agent i communicates the 'bad signal' conditional on the communication's cost.

The remaining case is when agents communicate both signal. We find that *Full Disclosure* is never a Nash Equilibrium in the communication stage. This result is intuitive. If communication is costly, agents never communicate both signal because always there is an incentive to deviate.

Through a numeric example, we analyze how the structure of communication equilibriums change for every $\widehat{e} \in (0,1)$ if the communication's cost increases. Consider $n = 10$, $p = -5$ and $h = 5,8$.

Figure 2. $\varepsilon = 0$

Suppose communication is costless (Figure 2). According to Preposition 5, *Full Disclosure* and *Partially Disclosure* are symmetric Nash Equilibriums for every $\widehat{e}$. Each agent strictly prefers to communicate her signal when $\widehat{e} \geq e_n$ and will be indifferent between communicate her signal or not when $e_n > \widehat{e}$. On the contrary, *Full Non-Disclosure* is a symmetric Nash Equilibrium only for $e_{n-1} > \widehat{e}$, where agents are indifferent between communicate or not. Then, when communication is costless agents have incentive to aggregate information.

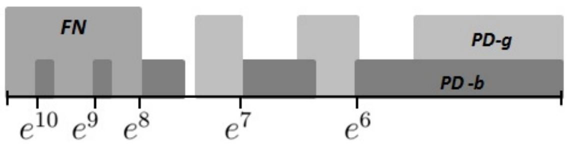

Figure 3. $\varepsilon = 0,45$

Suppose costly communication, with $\varepsilon = 0,45$ (Figure 3). In this case, *Full Disclosure* is not a symmetric Nash Equilibrium because agents have incentives to deviate and conceal information. Since communication is costly, they will never communicate both signals. In the other hand, *Full Non-Disclosure* is a symmetric Nash Equilibrium for higher levels of precision over the signal. For $e_{n-2} \geq \widehat{e}$, the communication's cost is greater than the expected benefit received from deviate after observing the 'bad signal', then each agent conceals both signals.

The interesting cases are the *Partially Disclosure*, which are symmetric Nash Equilibriums conditional on the level of precision over the signal. In the *Partially Disclosure-g*, agents deviate when the communication's cost is greater than the expected utility received after communicating the 'good signal'. For $\widehat{e} > e_{\frac{n}{2}+1}$, the expected utility received after communicating is increasing in the precision's signal, then *Partially Disclosure-g* is a symmetric Nash Equilibrium in the last part of the interval, where the expected utility is high enough, such that agents will communicate. For $e_{\frac{n}{2}+1} \geq \widehat{e} > e_n$, the expected utility received after communicating is increasing in the precision's signal in each interval $e_{N_g-1} \geq \widehat{e} > e_{N_g}$, where $N_g - 1 \geq \frac{n}{2} + 1$, then *Partially Disclosure-g* is a symmetric Nash Equilibrium in the last part of each interval. In the *Partially Disclosure-b*, agents deviate when the communication's cost is greater than the negative expected utility received after concealing the 'bad signal'. For $\widehat{e} > e_{\frac{n}{2}+1}$, the expected utility received after concealing the 'bad signal' is constant and equal to p, then agents communicate her signal if $-\varepsilon \geq p$. For $e_{\frac{n}{2}+1} \geq \widehat{e} > e_n$, the negative expected utility received after concealing is increasing in the precision's signal in each interval $e_{N_g-1} \geq \widehat{e} > e_{N_g}$, where $N_g - 1 \geq \frac{n}{2} + 1$, then *Partially Disclosure-b* is a symmetric Nash Equilibrium at the beginning of each interval.

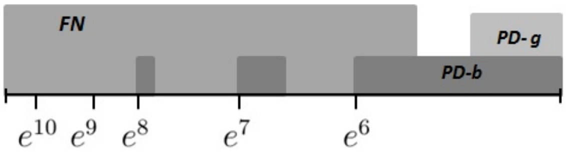

Figure 4. $\varepsilon = 0,75$

Suppose the communication's cost increases (Figure 4). In this case, *Full Non-Disclosure* is a symmetric Nash Equilibrium for higher levels of information. This is intuitive. Given the communication is costly, agents will have less incentive in communicate their signal, because the expected benefit receives from communicate decreases. Moreover, *Partially Disclosure-g* and *Partially Disclosure-b* are Nash Equilibriums only for higher levels of information, because only in that case the expected benefit from communicate is positive.

As we can see, costly communication change the symmetric Nash Equilibriums in the communication stage. And it is an interesting extension.

Chapter 5

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Appendix A

Proofs

A.1 Proof Proposition 1

Proof. Suppose $\widehat{e} \in (0,1)$ and $\phi_g = \phi_b = 0$. Since agents do not aggregate information, each agent will vote according to her private signal and the pivotal probability under unanimity rule. Let γ_S represents the probability that each agent votes for Y in state $S \in \{B, G\}$, then:

$$\gamma_G = \sigma_g \left(\frac{1+\widehat{e}}{2}\right) + \sigma_b \left(\frac{1-\widehat{e}}{2}\right)$$
$$\gamma_B = \sigma_g \left(\frac{1-\widehat{e}}{2}\right) + \sigma_b \left(\frac{1+\widehat{e}}{2}\right)$$

where σ_g and σ_b represent the probability that each agent votes for Y conditional on receiving the 'good signal' and the 'bad signal' respectively.
Under unanimity rule, for any symmetric strategy profile and for any given voter, we define $\mathbb{P}(piv|S)$ as the probability that $n-1$ other voters vote for Y in state $S \in \{B, G\}$. The probability that agent i is pivotal in state S is:

$$\mathbb{P}(piv|G) = \gamma_G^{n-1} = \left[\sigma_g \left(\frac{1+\widehat{e}}{2}\right) + \sigma_b \left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}$$

$$\mathbb{P}(piv|B) = \gamma_B^{n-1} = \left[\sigma_g \left(\frac{1-\widehat{e}}{2}\right) + \sigma_b \left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}$$

Let $\mathbb{E}U^g$ represent the expected utility that each agent receives from vote for Y after observing the 'good signal', then:

$$\mathbb{E}U^g = (p+h)\mathbb{P}(G|piv, s=g) + (p-h)\mathbb{P}(B|piv, s=g)$$
$$\Rightarrow \mathbb{E}U^g = (p+h)\frac{\gamma_G^{n-1}\left(\frac{1+\widehat{e}}{2}\right)}{\gamma_G^{n-1}\left(\frac{1+\widehat{e}}{2}\right)+\gamma_B^{n-1}\left(\frac{1-\widehat{e}}{2}\right)} + (p-h)\frac{\gamma_B^{n-1}\left(\frac{1-\widehat{e}}{2}\right)}{\gamma_G^{n-1}\left(\frac{1+\widehat{e}}{2}\right)+\gamma_B^{n-1}\left(\frac{1-\widehat{e}}{2}\right)}$$

Let $\mathbb{E}U^b$ represent the expected utility that each agent receives from vote for Y after observing the 'bad signal', then:

$$\mathbb{E}U^b = (p+h)\mathbb{P}(G|piv, s=b) + (p-h)\mathbb{P}(B|piv, s=b)$$
$$\Rightarrow \mathbb{E}U^b = (p+h)\frac{\gamma_G^{n-1}\left(\frac{1-\widehat{e}}{2}\right)}{\gamma_G^{n-1}\left(\frac{1-\widehat{e}}{2}\right)+\gamma_B^{n-1}\left(\frac{1+\widehat{e}}{2}\right)} + (p-h)\frac{\gamma_B^{n-1}\left(\frac{1+\widehat{e}}{2}\right)}{\gamma_G^{n-1}\left(\frac{1-\widehat{e}}{2}\right)+\gamma_B^{n-1}\left(\frac{1+\widehat{e}}{2}\right)}$$

Agent i strategy profile depends on $\mathbb{E}U^g$ and $\mathbb{E}U^b$, where:

$$\sigma_g = \begin{cases} 1 & \text{if } \mathbb{E}U^g > 0 \\ [0,1] & \text{if } \mathbb{E}U^g = 0 \\ 0 & \text{if } \mathbb{E}U^g < 0 \end{cases} \qquad \sigma_b = \begin{cases} 1 & \text{if } \mathbb{E}U^b > 0 \\ [0,1] & \text{if } \mathbb{E}U^b = 0 \\ 0 & \text{if } \mathbb{E}U^b < 0 \end{cases}$$

Note that $\sigma_g = 0$ and $\sigma_b = 0$ is always a symmetric Nash Equilibrium, since the pivotal probability is zero there is not incentive to deviate. It is easy to check that (0,1) and (1,1) are never a symmetric Nash Equilibriums in the voting stage and (1,0) is a symmetric Nash Equilibrium conditional on the effort decision.

Suppose $\sigma_g = 1$ and $\sigma_b = 0$ $\forall j \neq i$, then agent i votes $\sigma_g = 1$ if $\mathbb{E}U^g \geq 0$. This condition holds if and only if:

$$\widehat{e} \geq \frac{(h-p)^{\frac{1}{n}} - (p+h)^{\frac{1}{n}}}{(h-p)^{\frac{1}{n}} + (p+h)^{\frac{1}{n}}} = e_n$$

Suppose $\sigma_g = 1$ and $\sigma_b = 0$ $\forall j \neq i$, then agent i votes $\sigma_b = 0$ if $\mathbb{E}U^b \leq 0$. This condition holds if and only if:

$$\widehat{e} \leq \frac{(h-p)^{\frac{1}{n-2}} - (p+h)^{\frac{1}{n-2}}}{(h-p)^{\frac{1}{n-2}} + (p+h)^{\frac{1}{n-2}}} = e_{n-1}$$

Then, $\sigma_g = 1$ and $\sigma_b = 0$ is a Nash Equilibrium if $e_{n-1} \geq \widehat{e} \geq e_n$.

For a symmetric mixed strategy profile (σ_g, σ_b) to be an equilibrium, an agent who receives $s_i \in \{b, g\}$ must be indifferent between vote for Y and N. Agent i will be indifferent between vote for Y and vote for N whenever she receives signal $s_i \in \{b, g\}$ if and only if $\gamma_G = \gamma_B = 0$. Therefore, we check the mixed strategy profiles such that $\mathbb{E}U^g = 0$ or $\mathbb{E}U^b = 0$ hold.

Let $\mathbb{E}U^g = 0$, then:

$$\sigma_g = \frac{(h-p)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right) - (p+h)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)}{(p+h)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n}{n-1}} - (h-p)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n}{n-1}}}\sigma_b$$

or $\sigma_g = \alpha_1\sigma_b$.
The mixed strategy σ_g depends on $\widehat{e}$ and $\sigma_b \in \{0, 1\}$, where:

$$\sigma_g = \begin{cases} \alpha_1 > 0 & \text{if } \sigma_b = 1 \text{ and } \widehat{e} > e_n \\ \alpha_1 < 0 & \text{if } \sigma_b = 1 \text{ and } e_n > \widehat{e} \\ 0 & \text{if } \sigma_b = 0 \\ [0,1] & \text{if } \widehat{e} = e_n \end{cases}$$

Suppose $\sigma_b = 1$ and $\widehat{e} > e_n$, then we check the following cases:

- Suppose $\widehat{e} \geq -\frac{p}{h} > e_n$ and $\sigma_b = 1$, then $\sigma_g = \alpha_1 \in [0,1]$ $\forall j \neq i$. If $\mathbb{E}U^g = 0$ holds, then agent i votes $\sigma_b = 0$ since $\mathbb{E}U^b < 0$. Thus, $\sigma_g = \alpha_1$ and $\sigma_b = 1$ is not a Nash Equilibrium.
- Suppose $\widehat{e} = e_n$, then $\sigma_b = 0$ and $\sigma_g \in [0,1]$ $\forall j \neq i$. Agent i will be indifferent between vote for Y and vote for N whenever she receives signal $s_i = g$. If $\mathbb{E}U^g = 0$ holds, then agent i votes $\sigma_b = 0$ since $\mathbb{E}U^b < 0$. Thus, $\sigma_g = 1$ and $\sigma_b = 0$ is a Nash Equilibrium.

Let $\mathbb{E}U^b = 0$, then:

$$\sigma_b = \frac{(p+h)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right) - (h-p)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)}{(h-p)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n}{n-1}} - (p+h)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n}{n-1}}}\sigma_g$$

or $\sigma_b = \beta_1\sigma_g$.
The mixed strategy σ_b depends on $\widehat{e}$ and $\sigma_g \in \{0, 1\}$, where:

$$\sigma_b = \begin{cases} \beta_1 > 0 & \text{if } \sigma_g = 1 \text{ and } \widehat{e} > e_{n-1} \\ \beta_1 = 0 & \text{if } \sigma_g = 1 \text{ and } \widehat{e} = e_{n-1} \\ \beta_1 < 0 & \text{if } \sigma_g = 1 \text{ and } \widehat{e} < e_{n-1} \\ 0 & \text{if } \sigma_g = 0 \end{cases}$$

Therefore, we check the following cases:

- Suppose $\widehat{e} > e_{n-1}$ and $\sigma_g = 1$, then $\sigma_b = \beta_1 \in [0,1]$ $\forall j \neq i$. If $\mathbb{E}U^b = 0$ holds, then agent i votes $\sigma_g = 1$ since $\mathbb{E}U^g > 0$. Thus, $\sigma_g = 1$ and $\sigma_b = \beta_1$ is a Nash Equilibrium.

- Suppose $\widehat{e} = e_{n-1}$, then $\sigma_b = 0$ and $\sigma_g \in [0,1]$ $\forall j \neq i$. Agent i will be indifferent between vote for Y and vote for N whenever she receives signal $s_i = b$. If $\mathbb{E}U^b = 0$ holds, then agent i votes $\sigma_g = 1$ since $\mathbb{E}U^g > 0$. Thus, $\sigma_g = 1$ and $\sigma_b = 0$ is a Nash Equilibrium.

Consider e_n, it is easy to see that:

$$\frac{\partial e_n}{\partial p} = \frac{-2(p+h)^{\frac{1}{n}}(h-p)^{\frac{1}{n}}\left[\frac{1}{(h-p)} + \frac{1}{(p+h)}\right]}{n\left[(h-p)^{\frac{1}{n}} + (p+h)^{\frac{1}{n}}\right]^2} < 0$$

$$\frac{\partial e_n}{\partial h} = \frac{2(p+h)^{\frac{1}{n}}(h-p)^{\frac{1}{n}}\left[\frac{1}{(h-p)} - \frac{1}{(p+h)}\right]}{n\left[(h-p)^{\frac{1}{n}} + (p+h)^{\frac{1}{n}}\right]^2} < 0$$

$$\frac{\partial e_n}{\partial n} = \frac{2(p+h)^{\frac{1}{n}}(h-p)^{\frac{1}{n}}\left[Ln(p+h) - Ln(h-p)\right]}{n^2\left[(h-p)^{\frac{1}{n}} + (p+h)^{\frac{1}{n}}\right]^2} < 0$$

Consider e_{n-1}, it is easy to see that:

$$\frac{\partial e_{n-1}}{\partial p} = \frac{-2(p+h)^{\frac{1}{n-2}}(h-p)^{\frac{1}{n-2}}\left[\frac{1}{(h-p)} + \frac{1}{(p+h)}\right]}{(n-2)\left[(h-p)^{\frac{1}{n-2}} + (p+h)^{\frac{1}{n-2}}\right]^2} < 0$$

$$\frac{\partial e_{n-1}}{\partial h} = \frac{2(p+h)^{\frac{1}{n-2}}(h-p)^{\frac{1}{n-2}}\left[\frac{1}{(h-p)} - \frac{1}{(p+h)}\right]}{(n-2)\left[(h-p)^{\frac{1}{n-2}} + (p+h)^{\frac{1}{n-2}}\right]^2} < 0$$

$$\frac{\partial e_{n-1}}{\partial n} = \frac{2(p+h)^{\frac{1}{n-2}}(h-p)^{\frac{1}{n-2}}\left[Ln(p+h) - Ln(h-p)\right]}{(n-2)^2\left[(h-p)^{\frac{1}{n-2}} + (p+h)^{\frac{1}{n-2}}\right]^2} < 0$$

Consider the mixed strategy β_1, it is easy to see that:

$$\frac{\partial \beta_1}{\partial p} = \frac{2\widehat{e}(p+h)^{\frac{1}{n-1}}(h-p)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{1}{n-1}}\left[\frac{1}{(p+h)} + \frac{1}{(h-p)}\right]}{(n-1)\left[(h-p)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n}{n-1}} - (p+h)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n}{n-1}}\right]^2} > 0$$

$$\frac{\partial \beta_1}{\partial h} = \frac{2\widehat{e}(p+h)^{\frac{1}{n-1}}(h-p)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{1}{n-1}}\left[\frac{1}{(p+h)} - \frac{1}{(h-p)}\right]}{(n-1)\left[(h-p)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n}{n-1}} - (p+h)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n}{n-1}}\right]^2} > 0$$

$$\frac{\partial\beta_1}{\partial n} = \frac{-\widehat{e}(p+h)^{\frac{1}{n-1}}(h-p)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{1}{n-1}}}{(n-1)^2\left[(h-p)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n}{n-1}}-(p+h)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n}{n-1}}\right]^2}$$
$$\left[Ln(p+h)-Ln(h-p)+Ln\left(\frac{1-\widehat{e}}{2}\right)-Ln\left(\frac{1+\widehat{e}}{2}\right)\right]>0$$

$$\frac{\partial\beta_1}{\partial\left(\frac{1+\widehat{e}}{2}\right)} = \frac{(h-p)^{\frac{2}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{2}{n-1}}-(p+h)^{\frac{2}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{2}{n-1}}}{(n-1)\left[(h-p)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n}{n-1}}-(p+h)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n}{n-1}}\right]^2}+$$
$$\frac{2(p+h)^{\frac{1}{n-1}}(h-p)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{1}{n-1}}\left[\frac{1}{\left(\frac{1+\widehat{e}}{2}\right)}-\frac{1}{\left(\frac{1-\widehat{e}}{2}\right)}\right]\left[\left(\frac{1-\widehat{e}}{2}\right)^2-\left(\frac{1+\widehat{e}}{2}\right)^2\right]}{(n-1)\left[(h-p)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n}{n-1}}-(p+h)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n}{n-1}}\right]^2}>0$$

□

A.2 Proof Proposition 2

Proof. Suppose $\widehat{e} \in (0,1)$ and $\phi_g = \phi_b = 0\ \forall j \neq i$.

Case 1: Agent i deviates after observing the 'good signal'

Suppose agent i receives $s_i = g$ and she chooses $\phi_g = 1$. Let σ_g represent the probability that agent i votes for Y given that she observed the 'good signal'. On the other hand, the voting strategy for all other agents $j \neq i$ depends on their private information and agent i's signal. Let σ_{gg} and σ_{gb} represent the probability that agent $j \neq i$ votes for Y conditional on receiving the 'good signal' and the 'bad signal' respectively. The probability that each agent $j \neq i$ votes for Y in state S is:

$$\gamma^j_G = \sigma_{gg}\left(\frac{1+\widehat{e}}{2}\right)+\sigma_{gb}\left(\frac{1-\widehat{e}}{2}\right)$$

$$\gamma^j_B = \sigma_{gg}\left(\frac{1-\widehat{e}}{2}\right)+\sigma_{gb}\left(\frac{1+\widehat{e}}{2}\right)$$

Under unanimity rule, for any symmetric strategy profile and for any given voter, we define $\mathbb{P}(piv_j|S)$ as the probability that agent $j \neq i$ is pivotal in state S is:

$$\mathbb{P}(piv_j|G) = \sigma_g\gamma_G^{n-2} = \sigma_g\left[\sigma_{gg}\left(\frac{1+\widehat{e}}{2}\right)+\sigma_{gb}\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-2}$$

$$\mathbb{P}(piv_j|B) = \sigma_g \gamma_B^{n-2} = \sigma_g \left[\sigma_{gg}\left(\frac{1-\widehat{e}}{2}\right) + \sigma_{gb}\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-2}$$

The probability that agent i is pivotal in state S is:

$$\mathbb{P}(piv_i|G) = \gamma_G^{n-1} = \left[\sigma_{gg}\left(\frac{1+\widehat{e}}{2}\right) + \sigma_{gb}\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}$$

$$\mathbb{P}(piv_i|B) = \gamma_B^{n-1} = \left[\sigma_{gg}\left(\frac{1-\widehat{e}}{2}\right) + \sigma_{bb}\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}$$

Let $\mathbb{E}U_i^g$ represent the expected utility that agent i receives from vote for Y after observing the 'good signal', then:

$$\mathbb{E}U_i^g = (p+h)\mathbb{P}(G|piv_i, s_i = g) + (p-h)\mathbb{P}(B|piv_i, s_i = g)$$

$$\Rightarrow \mathbb{E}U_i^g = (p+h)\frac{\gamma_G^{n-1}\left(\frac{1+\widehat{e}}{2}\right)}{\gamma_G^{n-1}\left(\frac{1+\widehat{e}}{2}\right) + \gamma_B^{n-1}\left(\frac{1-\widehat{e}}{2}\right)} + (p-h)\frac{\gamma_B^{n-1}\left(\frac{1-\widehat{e}}{2}\right)}{\gamma_G^{n-1}\left(\frac{1+\widehat{e}}{2}\right) + \gamma_B^{n-1}\left(\frac{1-\widehat{e}}{2}\right)}$$

Let $\mathbb{E}U_j^{gg}$ represent the expected utility that agent $j \neq i$ receives from vote for Y after observing the 'good signal', then:

$$\mathbb{E}U_j^{gg} = (p+h)\mathbb{P}(G|piv_j, s_i = g, s_j = g) + (p-h)\mathbb{P}(B|piv_j, s_i = g, s_j = g)$$

$$\Rightarrow \mathbb{E}U_j^{gg} = (p+h)\frac{\gamma_G^{n-2}\sigma_g\left(\frac{1+\widehat{e}}{2}\right)^2}{\gamma_G^{n-2}\sigma_g\left(\frac{1+\widehat{e}}{2}\right)^2 + \gamma_B^{n-2}\sigma_g\left(\frac{1-\widehat{e}}{2}\right)^2} + (p-h)\frac{\gamma_B^{n-2}\sigma_g\left(\frac{1-\widehat{e}}{2}\right)^2}{\gamma_G^{n-2}\sigma_g\left(\frac{1+\widehat{e}}{2}\right)^2 + \gamma_B^{n-2}\sigma_g\left(\frac{1-\widehat{e}}{2}\right)^2}$$

Let $\mathbb{E}U_j^{gb}$ represent the expected utility that agent $j \neq i$ receives from vote for Y after observing the 'bad signal', then:

$$\mathbb{E}U_j^{gb} = (p+h)\mathbb{P}(G|piv_j, s_i = g, s_j = b) + (p-h)\mathbb{P}(B|piv_i, s_i = g, s_j = b)$$

$$\Rightarrow \mathbb{E}U_j^{gb} = (p+h)\frac{\gamma_G^{n-2}\sigma_g}{\gamma_G^{n-2}\sigma_g + \gamma_B^{n-2}\sigma_g} + (p-h)\frac{\gamma_B^{n-2}\sigma_g}{\gamma_G^{n-2}\sigma_g + \gamma_B^{n-2}\sigma_g}$$

Agent i strategy profile depends on $\mathbb{E}U_i^g$, where:

$$\sigma_g = \begin{cases} 1 & \text{if } \mathbb{E}U_i^g > 0 \\ [0,1] & \text{if } \mathbb{E}U_i^g = 0 \\ 0 & \text{if } \mathbb{E}U_i^g < 0 \end{cases}$$

Agent $j \neq i$ strategy profile depends on $\mathbb{E}U_j^{gg}$ and $\mathbb{E}U_j^{gb}$, where:

$$\sigma_{gg} = \begin{cases} 1 & \text{if } \mathbb{E}U_j^{gg} > 0 \\ [0,1] & \text{if } \mathbb{E}U_j^{gg} = 0 \\ 0 & \text{if } \mathbb{E}U_j^{gg} < 0 \end{cases} \qquad \sigma_{gb} = \begin{cases} 1 & \text{if } \mathbb{E}U_j^{gb} > 0 \\ [0,1] & \text{if } \mathbb{E}U_j^{gb} = 0 \\ 0 & \text{if } \mathbb{E}U_j^{gb} < 0 \end{cases}$$

Note that $\sigma_g = 0$, $\sigma_{gg} = 0$ and $\sigma_{gb} = 0$ is always a symmetric Nash Equilibrium, since the pivotal probability is zero there is not incentive to deviate. We focus in strategy profiles where the project is implemented with strictly positive probability, where it is easy to check that (1,1,1) and (1,0,1) are never symmetric Nash Equilibrium in the voting stage. We find that (1,1,0) is a symmetric Nash Equilibrium conditional on the effort decision.

Suppose $\sigma_{gg} = 1$ and $\sigma_{gb} = 0$, then agent i votes $\sigma_g = 1$ if $\mathbb{E}U_i^g \geq 0$. This condition holds if and only if:

$$\widehat{e} \geq \frac{(h-p)^{\frac{1}{n}} - (p+h)^{\frac{1}{n}}}{(h-p)^{\frac{1}{n}} + (p+h)^{\frac{1}{n}}} = e_n$$

Suppose $\sigma_g = 1$, $\sigma_{gg} = 1$ and $\sigma_{gb} = 0$, then agent j votes $\sigma_{gg} = 1$ if $\mathbb{E}U_j^{gg} \geq 0$. This condition holds if and only if:

$$\widehat{e} \geq \frac{(h-p)^{\frac{1}{n}} - (p+h)^{\frac{1}{n}}}{(h-p)^{\frac{1}{n}} + (p+h)^{\frac{1}{n}}} = e_n$$

Suppose $\sigma_g = 1$, $\sigma_{gg} = 1$ and $\sigma_{gb} = 0$, then agent j votes $\sigma_{gb} = 0$ if $\mathbb{E}U_j^{gb} \leq 0$. This condition holds if and only if:

$$\widehat{e} \leq \frac{(h-p)^{\frac{1}{n-2}} - (p+h)^{\frac{1}{n-2}}}{(h-p)^{\frac{1}{n-2}} + (p+h)^{\frac{1}{n-2}}} = e_{n-1}$$

Then $\sigma_g = 1$, $\sigma_{gg} = 1$ and $\sigma_{gb} = 0$ is a Nash Equilibrium if $e_{n-1} \geq \widehat{e} \geq e_n$.

For a mixed strategy profile $(\sigma_g, \sigma_{gg}, \sigma_{gb})$ to be an equilibrium, an agent who receives the 'good signal' or the 'bad signal' must be indifferent between vote for Y and N. Agent i will be indifferent between vote for Y and vote for N when she receives signal $s_i = g$ if $\mathbb{E}U_i^g = 0$. On the other hand, agent $j \neq i$ will be indifferent between vote for Y and vote for N whenever she receives signal $s_j \in \{b, g\}$ if $\mathbb{E}U_j^{gg} = 0$ and $\mathbb{E}U_j^{gb} = 0$.

It is easy to see that these three equalities hold simultaneously if and only if $\gamma_G = \gamma_B = 0$. Note that, if $\sigma_g = 0$, then $\mathbb{E}U_j^{gg} = 0$ and $\mathbb{E}U_j^{gb} = 0$. Therefore, we check the mixed strategy profiles such that $\mathbb{E}U_j^{gg} = 0$ or $\mathbb{E}U_j^{gb} = 0$ hold when $\sigma_g > 0$.

Let $\mathbb{E}U_j^{gg} = 0$, then:

$$\sigma_{gg} = \frac{(h-p)^{\frac{1}{n-2}} \left(\frac{1-\widehat{e}}{2}\right)^{\frac{2}{n-2}} \left(\frac{1+\widehat{e}}{2}\right) - (p+h)^{\frac{1}{n-2}} \left(\frac{1+\widehat{e}}{2}\right)^{\frac{2}{n-2}} \left(\frac{1-\widehat{e}}{2}\right)}{(p+h)^{\frac{1}{n-2}} \left(\frac{1+\widehat{e}}{2}\right)^{\frac{k}{n-2}} - (h-p)^{\frac{1}{n-2}} \left(\frac{1-\widehat{e}}{2}\right)^{\frac{k}{n-2}}} \sigma_{gb}$$

or $\sigma_{gg} = \alpha_2 \sigma_{gb}$.
The mixed strategy σ_{gg} depends on $\widehat{e}$ and $\sigma_{gb} \in \{0, 1\}$, where:

$$\sigma_{gg} = \begin{cases} \alpha_2 > 0 & \text{if } \sigma_{gb} = 1 \text{ and } \widehat{e} > e_n \\ \alpha_2 < 0 & \text{if } \sigma_{gb} = 1 \text{ and } e_n > \widehat{e} \\ 0 & \text{if } \sigma_{gb} = 0 \\ [0,1] & \text{if } \widehat{e} = e_n \end{cases}$$

Suppose $\sigma_{gb} = 1$ and $\widehat{e} > e_n$, then we check the following cases:

- Suppose $\widehat{e} \geq \frac{(h-p)^{\frac{1}{2}} - (p+h)^{\frac{1}{2}}}{(h-p)^{\frac{1}{2}} + (p+h)^{\frac{1}{2}}} > e_n$ and $\sigma_{gb} = 1$, then $\sigma_{gg} = \alpha_2 \in [0, 1]$. If $\mathbb{E}U_j^{gg} = 0$ holds, then $\sigma_{gb} = 0$ since $\mathbb{E}U_j^{gb} < 0$. Thus, $\sigma_g = 1$, $\sigma_{gg} = \alpha_2$ and $\sigma_{gb} = 1$ is not a Nash Equilibrium.

- Suppose $\widehat{e} = e_n$, then $\sigma_{gb} = 0$ and $\sigma_{gg} \in [0, 1]$. Agent j will be indifferent between vote for Y and vote for N whenever she receives signal $s_j = g$. If $\mathbb{E}U_j^{gg} = 0$ holds, then $\sigma_g = 1$ and $\sigma_{gb} = 0$ since $\mathbb{E}U_i^g > 0$ and $\mathbb{E}U_j^{gb} < 0$. Thus, $\sigma_g = 1$, $\sigma_{gg} = 1$ and $\sigma_{gb} = 0$ is a Nash Equilibrium.

Let $\mathbb{E}U_j^{gb} = 0$, then:

$$\sigma_{gb} = \frac{(p+h)^{\frac{1}{n-2}} \left(\frac{1+\widehat{e}}{2}\right) - (h-p)^{\frac{1}{n-2}} \left(\frac{1-\widehat{e}}{2}\right)}{(h-p)^{\frac{1}{n-2}} \left(\frac{1+\widehat{e}}{2}\right) - (p+h)^{\frac{1}{n-2}} \left(\frac{1-\widehat{e}}{2}\right)} \sigma_{gg}$$

or $\sigma_{gb} = \beta_2 \sigma_{gg}$.
The mixed strategy σ_{gb} depends on $\widehat{e}$ and $\sigma_{gg} \in \{0, 1\}$, where:

$$\sigma_{gb} = \begin{cases} \beta_2 > 0 & \text{if } \sigma_{gg} = 1 \text{ and } \widehat{e} > e_{n-1} \\ \beta_2 = 0 & \text{if } \sigma_{gg} = 1 \text{ and } \widehat{e} = e_{n-1} \\ \beta_2 < 0 & \text{if } \sigma_{gg} = 1 \text{ and } \widehat{e} < e_{n-1} \\ 0 & \text{if } \sigma_{gg} = 0 \end{cases}$$

Therefore, we check the following cases:

- Suppose $\widehat{e} > e_{n-1}$ and $\sigma_{gg} = 1$, then $\sigma_{gb} = \beta_2 \in [0, 1]$. If $\mathbb{E}U_j^{gb} = 0$ holds, then $\sigma_g = 1$ and $\sigma_{gg} = 1$ since $\mathbb{E}U_i^g > 0$ and $\mathbb{E}U_j^{gg} > 0$. Thus, $\sigma_g = 1$, $\sigma_{gg} = 1$ and $\sigma_{gb} = \beta_2$ is a Nash Equilibrium.

- Suppose $\widehat{e} = e_{n-1}$, then $\sigma_{gb} = 0$ and $\sigma_{gg} \in [0, 1]$. Agent i will be indifferent between vote for Y and vote for N whenever she receives signal $s_i = b$. If $\mathbb{E}U_j^{gb} = 0$ holds, then $\sigma_g = 1$ and $\sigma_{gg} = 1$ since $\mathbb{E}U_i^g > 0$ and $\mathbb{E}U_j^{gg} > 0$. Thus, $\sigma_g = 1$, $\sigma_{gg} = 1$ and $\sigma_{gb} = 0$ is a Nash Equilibrium.

Consider the mixed strategy β_2, it is easy to see that:

$$\frac{\partial \beta_2}{\partial p} = \frac{\widehat{e}(p+h)^{\frac{1}{n-2}}(h-p)^{\frac{1}{n-2}}\left[\frac{1}{(p+h)} + \frac{1}{(h-p)}\right]}{(n-2)\left[(h-p)^{\frac{1}{n-2}}\left(\frac{1+\widehat{e}}{2}\right) - (p+h)^{\frac{1}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)\right]^2} > 0$$

$$\frac{\partial \beta_2}{\partial h} = \frac{\widehat{e}(p+h)^{\frac{1}{n-2}}(h-p)^{\frac{1}{n-2}}\left[\frac{1}{(p+h)} - \frac{1}{(h-p)}\right]}{(n-2)\left[(h-p)^{\frac{1}{n-2}}\left(\frac{1+\widehat{e}}{2}\right) - (p+h)^{\frac{1}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)\right]^2} > 0$$

$$\frac{\partial \beta_2}{\partial n} = \frac{\widehat{e}(p+h)^{\frac{1}{n-2}}(h-p)^{\frac{1}{n-2}}\left[Ln(h-p) - Ln(p+h)\right]}{(n-2)^2\left[(h-p)^{\frac{1}{n-2}}\left(\frac{1+\widehat{e}}{2}\right) - (p+h)^{\frac{1}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)\right]^2} > 0$$

$$\frac{\partial \beta_2}{\partial\left(\frac{1+\widehat{e}}{2}\right)} = \frac{\left[(p+h)^{\frac{1}{n-2}} + (h-p)^{\frac{1}{n-2}}\right]\left[(h-p)^{\frac{1}{n-2}} - (p+h)^{\frac{1}{n-2}}\right]}{\left[(h-p)^{\frac{1}{n-2}}\left(\frac{1+\widehat{e}}{2}\right) - (p+h)^{\frac{1}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)\right]^2} > 0$$

Case 2: Agent i deviates after observing the 'bad signal'

Suppose agent i receives $s_i = b$ and she chooses $\phi_b = 1$. Let σ_b represent the probability that agent i votes for Y given that she observed the 'bad signal'. Let σ_{bg} and σ_{bb} represents the probability that agent $j \neq i$ votes for Y conditional on receiving the 'good signal' and the 'bad signal' respectively. The probability that each agent $j \neq i$ votes for Y in state S is:

$$\gamma_G^j = \sigma_{bg}\left(\frac{1+\widehat{e}}{2}\right) + \sigma_{bb}\left(\frac{1-\widehat{e}}{2}\right)$$

$$\gamma_B^j = \sigma_{bg}\left(\frac{1-\widehat{e}}{2}\right) + \sigma_{bb}\left(\frac{1+\widehat{e}}{2}\right)$$

Under unanimity rule, for any symmetric strategy profile and for any given voter, we define $\mathbb{P}(piv_j|S)$ as the probability that agent $j \neq i$ is pivotal in state S is:

$$\mathbb{P}(piv_j|G) = \sigma_b \gamma_G^{n-2} = \sigma_b \left[\sigma_{bg}\left(\frac{1+\widehat{e}}{2}\right) + \sigma_{bb}\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-2}$$

$$\mathbb{P}(piv_j|B) = \sigma_b \gamma_B^{n-2} = \sigma_b \left[\sigma_{bg}\left(\frac{1-\widehat{e}}{2}\right) + \sigma_{bb}\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-2}$$

The probability that agent i is pivotal in state S is:

$$\mathbb{P}(piv_i|G = \gamma_G^{n-1} = \left[\sigma_{bg}\left(\frac{1+\widehat{e}}{2}\right) + \sigma_{bb}\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}$$

$$\mathbb{P}(piv_i|B) = \gamma_B^{n-1} = \left[\sigma_{bg}\left(\frac{1-\widehat{e}}{2}\right) + \sigma_{bb}\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}$$

Let $\mathbb{E}U_i^b$ represent the expected utility that agent i receives from vote for Y after observing the 'bad signal', then:

$$\mathbb{E}U_i^b = (p+h)\mathbb{P}(G|piv_i, s_i = b) + (p-h)\mathbb{P}(B|piv_i, s_i = b)$$

$$\Rightarrow \mathbb{E}U_i^b = (p+h)\frac{\gamma_G^{n-1}\left(\frac{1-\widehat{e}}{2}\right)}{\gamma_G^{n-1}\left(\frac{1-\widehat{e}}{2}\right) + \gamma_B^{n-1}\left(\frac{1+\widehat{e}}{2}\right)} + (p-h)\frac{\gamma_B^{n-1}\left(\frac{1+\widehat{e}}{2}\right)}{\gamma_G^{n-1}\left(\frac{1-\widehat{e}}{2}\right) + \gamma_B^{n-1}\left(\frac{1+\widehat{e}}{2}\right)}$$

Let $\mathbb{E}U_j^{bg}$ represent the expected utility that agent $j \neq i$ receives from vote for Y after observing the 'good signal', then:

$$\mathbb{E}U_j^{bg} = (p+h)\mathbb{P}(G|piv_j, s_i = b, s_j = g) + (p-h)\mathbb{P}(B|piv_j, s_i = b, s_j = g)$$

$$\Rightarrow \mathbb{E}U_j^{bg} = (p+h)\frac{\gamma_G^{n-2}\sigma_b}{\gamma_G^{n-2}\sigma_b + \gamma_B^{n-2}\sigma_b} + (p-h)\frac{\gamma_B^{n-2}\sigma_b}{\gamma_G^{n-2}\sigma_b + \gamma_B^{n-2}\sigma_b}$$

Let $\mathbb{E}U_j^{bb}$ represent the expected utility that agent $j \neq i$ receives from vote for Y after observing signal the 'bad signal', then:

$$\mathbb{E}U_j^{bb} = (p+h)\mathbb{P}(G|piv_j, s_i = b, s_j = b) + (p-h)\mathbb{P}(B|piv_j, s_i = b, s_j = b)$$

$$\Rightarrow \mathbb{E}U_j^{bb} = (p+h)\frac{\gamma_G^{n-2}\sigma_b\left(\frac{1-\widehat{e}}{2}\right)^2}{\gamma_G^{n-2}\sigma_b\left(\frac{1-\widehat{e}}{2}\right)^2+\gamma_B^{n-2}\sigma_b\left(\frac{1+\widehat{e}}{2}\right)^2} + (p-h)\frac{\gamma_B^{n-2}\sigma_b\left(\frac{1+\widehat{e}}{2}\right)^2}{\gamma_G^{n-2}\sigma_b\left(\frac{1-\widehat{e}}{2}\right)^2+\gamma_B^{n-2}\sigma_b\left(\frac{1+\widehat{e}}{2}\right)^2}$$

Agent i strategy profile depends on $\mathbb{E}U_i^b$, where:

$$\sigma_b = \begin{cases} 1 & \text{if } \mathbb{E}U_i^b > 0 \\ [0,1] & \text{if } \mathbb{E}U_i^b = 0 \\ 0 & \text{if } \mathbb{E}U_i^b < 0 \end{cases}$$

Agent $j \neq i$ strategy profile depends on $\mathbb{E}U_j^{bg}$ and $\mathbb{E}U_j^{bb}$, where:

$$\sigma_{bg} = \begin{cases} 1 & \text{if } \mathbb{E}U_j^{bg} > 0 \\ [0,1] & \text{if } \mathbb{E}U_j^{bg} = 0 \\ 0 & \text{if } \mathbb{E}U_j^{bg} < 0 \end{cases} \qquad \sigma_{bb} = \begin{cases} 1 & \text{if } \mathbb{E}U_j^{bb} > 0 \\ [0,1] & \text{if } \mathbb{E}U_j^{bb} = 0 \\ 0 & \text{if } \mathbb{E}U_j^{bb} < 0 \end{cases}$$

It is easy to see that $\sigma_b = 0$, $\sigma_{bg} = 0$ and $\sigma_{bb} = 0$ is a Nash Equilibrium, since the pivotal probability is zero there is not incentive to deviate. We focus in strategy profiles where the project is implemented with strictly positive probability, where it is easy to check that (1,1,1) and (1,0,1) are never symmetric Nash Equilibrium in the voting stage. We find that (1,1,0) is a symmetric Nash Equilibrium conditional on the effort decision.
Suppose $\sigma_{bg} = 1$ and $\sigma_{bb} = 0$, then $\sigma_b = 1$ if $\mathbb{E}U_i^b \geq 0$. This condition holds if and only if:

$$\widehat{e} \geq \frac{(h-p)^{\frac{1}{n-2}} - (p+h)^{\frac{1}{n-2}}}{(h-p)^{\frac{1}{n-2}} + (p+h)^{\frac{1}{n-2}}} = e_{n-1}$$

Suppose $\sigma_b = 1$, $\sigma_{bg} = 1$ and $\sigma_{bb} = 0$ $\forall j \neq k$, then agent k votes $\sigma_{bg} = 1$ if $\mathbb{E}U_k^{bg} \geq 0$. This condition holds if and only if:

$$\widehat{e} \geq \frac{(h-p)^{\frac{1}{n-2}} - (p+h)^{\frac{1}{n-2}}}{(h-p)^{\frac{1}{n-2}} + (p+h)^{\frac{1}{n-2}}} = e_{n-1}$$

Suppose $\sigma_b = 1$, $\sigma_{bg} = 1$ and $\sigma_{bb} = 0$ $\forall j \neq k$, then agent k votes $\sigma_{bb} = 0$ if $\mathbb{E}U_k^{bb} \leq 0$. This condition holds if and only if:

$$\widehat{e} \leq \frac{(h-p)^{\frac{1}{n-4}} - (p+h)^{\frac{1}{n-4}}}{(h-p)^{\frac{1}{n-4}} + (p+h)^{\frac{1}{n-4}}} = e_{n-2}$$

Then $\sigma_b = 1$, $\sigma_{bg} = 1$ and $\sigma_{bb} = 0$ is a Nash Equilibrium if $e_{n-2} \geq \widehat{e} \geq e_{n-1}$.
For a mixed strategy profile $(\sigma_b, \sigma_{bg}, \sigma_{bb})$ to be an equilibrium, an agent who receives the 'good signal' or the 'bad signal' must be indifferent between vote for Y and N. Agent i will be indifferent between vote for Y and vote for N when she receives signal $s_i = b$ if $\mathbb{E}U_i^b = 0$. On the other hand, agent $j \neq i$ will be indifferent between vote for Y and vote for N whenever she receives signal $s_j \in \{b, g\}$ if $\mathbb{E}U_j^{bg} = 0$ and $\mathbb{E}U_j^{bb} = 0$.
It is easy to see that these three equalities hold simultaneously if and only if $\gamma_G = \gamma_B = 0$. Note that, if $\sigma_b = 0$, then $\mathbb{E}U_j^{bg} = 0$ and $\mathbb{E}U_j^{bb} = 0$. Therefore, we check the mixed strategy profiles such that $\mathbb{E}U_j^{bg} = 0$ or $\mathbb{E}U_j^{bb} = 0$ hold when $\sigma_b > 0$.

Let $\mathbb{E}U_j^{bg} = 0$, then:

$$\sigma_{bg} = \frac{(h-p)^{\frac{1}{n-2}}\left(\frac{1+\widehat{e}}{2}\right) - (p+h)^{\frac{1}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)}{(p+h)^{\frac{1}{n-2}}\left(\frac{1+\widehat{e}}{2}\right) - (h-p)^{\frac{1}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)}\sigma_{bb}$$

or $\sigma_{bg} = \alpha_3 \sigma_{bb}$.
The mixed strategy σ_{bg} depends on $\widehat{e}$ and $\sigma_{bb} \in \{0, 1\}$, where:

$$\sigma_{bg} = \begin{cases} \alpha_3 > 0 & \text{if } \sigma_{bg} = 1 \text{ and } \widehat{e} > e_{n-1} \\ \alpha_3 < 0 & \text{if } \sigma_{bg} = 1 \text{ and } e_{n-1} > \widehat{e} \\ 0 & \text{if } \sigma_{bg} = 0 \\ [0,1] & \text{if } \widehat{e} = e_{n-1} \end{cases}$$

Suppose $\sigma_{bb} = 1$ and $\widehat{e} > e_{n-1}$, then $\alpha \in]1, +\infty[$. Therefore, we check the following case:

- Suppose $\widehat{e} = e_{n-1}$, then $\sigma_{bb} = 0$ and $\sigma_{bg} \in [0, 1]$ $\forall j \neq k$. Agent k will be indifferent between vote for Y and vote for N whenever she receives signal $s_k = g$. If $\mathbb{E}U_k^{bg} = 0$ holds, then $\sigma_b = 1$ and $\sigma_{bg} = 0$ since $\mathbb{E}U_i^g > 0$ and $\mathbb{E}U_k^{bb} < 0$. Thus, $\sigma_b = 1$, σ_{bb} and $\sigma_{bg} = 0$ is a Nash Equilibrium.

Let $\mathbb{E}U_j^{bb} = 0$, then:

$$\sigma_{bb} = \frac{(p+h)^{\frac{1}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{2}{n-2}}\left(\frac{1+\widehat{e}}{2}\right) - (h-p)^{\frac{1}{n-2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{2}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)}{(h-p)^{\frac{1}{n-2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n}{n-2}} - (p+h)^{\frac{1}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n}{n-2}}}\sigma_{bg}$$

or $\sigma_{bb} = \beta_3 \sigma_{bg}$.
The mixed strategy σ_{bb} depends on $\widehat{e}$ and $\sigma_{bg} \in \{0, 1\}$, where:

$$\sigma_{bb} = \begin{cases} \beta_3 > 0 & \text{if } \sigma_{bg} = 1 \text{ and } \widehat{e} > e_{n-2} \\ \beta_3 = 0 & \text{if } \sigma_{bg} = 1 \text{ and } \widehat{e} = e_{n-2} \\ \beta_3 < 0 & \text{if } \sigma_{bg} = 1 \text{ and } \widehat{e} < e_{n-2} \\ 0 & \text{if } \sigma_{bg} = 0 \end{cases}$$

Therefore, we check the following cases:

- Suppose $\widehat{e} > e_{n-2}$ and $\sigma_{bg} = 1$, then $\sigma_{bb} = \beta_3 \in [0,1]$ $\forall j \neq k$. If $\mathbb{E}U_k^{bb} = 0$ holds, then $\sigma_b = 1$ and $\sigma_{bg} = 1$ since $\mathbb{E}U_i^b > 0$ and $\mathbb{E}U_k^{bg} > 0$. Thus, $\sigma_b = 1$, $\sigma_{bg} = 1$ and $\sigma_{bb} = \beta_3$ is a Nash Equilibrium.

- Suppose $\widehat{e} = e_{n-2}$, then $\sigma_{bb} = 0$ and $\sigma_{bg} \in [0,1]$ $\forall j \neq k$. Agent i will be indifferent between vote for Y and vote for N whenever she receives signal $s_i = b$. If $\mathbb{E}U_k^{bb} = 0$ holds, then $\sigma_b = 1$ and $\sigma_{bg} = 1$ since $\mathbb{E}U_i^b) > 0$ and $\mathbb{E}U_k^{bg} > 0$. Thus, $\sigma_b = 1$, $\sigma_{bg} = 1$ and $\sigma_{bb} = 0$ is a Nash Equilibrium.

Consider e_{n-2}, it is easy to see that:

$$\frac{\partial e_{n-2}}{\partial p} = \frac{-2(p+h)^{\frac{1}{n-4}}(h-p)^{\frac{1}{n-4}}\left[\frac{1}{(h-p)} + \frac{1}{(p+h)}\right]}{(n-4)\left[(h-p)^{\frac{1}{n-4}} + (p+h)^{\frac{1}{n-4}}\right]^2} < 0$$

$$\frac{\partial e_{n-2}}{\partial h} = \frac{2(p+h)^{\frac{1}{n-4}}(h-p)^{\frac{1}{n-4}}\left[\frac{1}{(h-p)} - \frac{1}{(p+h)}\right]}{(n-4)\left[(h-p)^{\frac{1}{n-4}} + (p+h)^{\frac{1}{n-4}}\right]^2} < 0$$

$$\frac{\partial e_{n-2}}{\partial n} = \frac{2(p+h)^{\frac{1}{n-4}}(h-p)^{\frac{1}{n-4}}\left[Ln(p+h) - Ln(h-p)\right]}{(n-4)^2\left[(h-p)^{\frac{1}{n-4}} + (p+h)^{\frac{1}{n-4}}\right]^2} < 0$$

Consider the mixed strategy β_3, it is easy to see that:

$$\frac{\partial \beta_3}{\partial p} = \frac{2\widehat{e}(p+h)^{\frac{1}{n-2}}(h-p)^{\frac{1}{n-2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{2}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{2}{n-2}}\left[\frac{1}{(p+h)} + \frac{1}{(h-p)}\right]}{(n-2)\left[(h-p)^{\frac{1}{n-2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n}{n-2}} - (p+h)^{\frac{1}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n}{n-2}}\right]^2} > 0$$

$$\frac{\partial \beta_3}{\partial h} = \frac{2\widehat{e}(p+h)^{\frac{1}{n-2}}(h-p)^{\frac{1}{n-2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{2}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{2}{n-2}}\left[\frac{1}{(p+h)} - \frac{1}{(h-p)}\right]}{(n-2)\left[(h-p)^{\frac{1}{n-2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n}{n-2}} - (p+h)^{\frac{1}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n}{n-2}}\right]^2} > 0$$

$$\frac{\partial \beta_3}{\partial n} = \frac{-\widehat{e}(p+h)^{\frac{1}{n-1}}(h-p)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{1}{n-1}}}{(n-1)^2\left[(h-p)^{\frac{1}{n-1}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n}{n-1}} - (p+h)^{\frac{1}{n-1}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n}{n-1}}\right]^2}$$
$$\left[Ln(p+h) - Ln(h-p) + Ln\left(\frac{1-\widehat{e}}{2}\right)) - Ln\left(\frac{1+\widehat{e}}{2}\right)\right] > 0$$

$$\frac{\partial \beta_3}{\partial\left(\frac{1+\widehat{e}}{2}\right)} = \frac{(h-p)^{\frac{2}{n-2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{4}{n-2}} - (p+h)^{\frac{2}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{4}{n-2}}}{(n-2)\left[(h-p)^{\frac{1}{n-2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n}{n-2}} - (p+h)^{\frac{1}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n}{n-2}}\right]^2} +$$
$$\frac{2(p+h)^{\frac{1}{n-2}}(h-p)^{\frac{1}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{2}{n-2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{2}{n-2}}\left[\frac{1}{\left(\frac{1+\widehat{e}}{2}\right)} - \frac{1}{\left(\frac{1-\widehat{e}}{2}\right)}\right]}{(n-2)\left[(h-p)^{\frac{1}{n-2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n}{n-2}} - (p+h)^{\frac{1}{n-2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n}{n-2}}\right]^2}\left[\left(\frac{1-\widehat{e}}{2}\right)^2 - \left(\frac{1+\widehat{e}}{2}\right)^2\right] > 0$$

□

A.3 Proof Proposition 3

Proof. Suppose $\widehat{e} \in (0,1)$. We check the equilibriums in each case:

I) Consider $\phi_g = \phi_b = 1$. Since agents aggregate information, agent i's pivotal probability is the same under any voting rule. Suppose agent i is pivotal and let $\mathbb{E}U$ represent the expected utility that agent i receives from vote for Y after observing N_g and N_b, then:

$$\mathbb{E}U = (p+h)\mathbb{P}(G|N_g, N_b) + (p-h)\mathbb{P}(B|N_g, N_b)$$

Agent i strategy profile depends on $\mathbb{E}U$, where:

$$\sigma = \begin{cases} 1 & \text{if } \mathbb{E}U > 0 \\ [0,1] & \text{if } \mathbb{E}U = 0 \\ 0 & \text{if } \mathbb{E}U < 0 \end{cases}$$

We have a necessary, but not sufficient, condition over N_g (or equivalently N_b) such that agent i will be willing to voter for Y:

$$(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{2N_g-n} \geq (h-p)\left(\frac{1-\widehat{e}}{2}\right)^{2N_g-n}$$

This inequality holds if $N_g > \frac{n}{2}$. Then for n even $N_g \geq \frac{n}{2}+1$ and $N_g \geq \frac{n+1}{2}$ for n odd. Suppose that the prior inequalities hold, then we have a condition over $\widehat{e}$ such that agent i will vote for Y:

$$\widehat{e} > \frac{(h-p)^{\frac{1}{2N_g-n}} - (p+h)^{\frac{1}{2N_g-n}}}{(h-p)^{\frac{1}{2N_g-n}} + (p+h)^{\frac{1}{2N_g-n}}} = e_{N_g}$$

II) Consider $\phi_g = 1$ and $\phi_b = 0$. Since agents aggregate information, agent i can infer N_b from N_g and the symmetric Nash equilibrium is the same as I).

III) Consider $\phi_g = 0$ and $\phi_b = 1$. Since agents aggregate information, agent i can infer N_g from N_b and the symmetric Nash equilibrium is the same as I).

Suppose $N_g \geq \frac{n}{2}+1$ or $N_g \geq \frac{n+1}{2}$ hold, then:

$$\frac{\partial e_{N_g}}{\partial p} = \frac{-2(p+h)^{\frac{1}{2N_g-n}}(h-p)^{\frac{1}{2N_g-n}}\left[\frac{1}{(h-p)}+\frac{1}{(p+h)}\right]}{(2N_g-n)\left[(h-p)^{\frac{1}{2N_g-n}}+(p+h)^{\frac{1}{2N_g-n}}\right]^2} < 0$$

$$\frac{\partial e_{N_g}}{\partial h} = \frac{2(p+h)^{\frac{1}{2N_g-n}}(h-p)^{\frac{1}{2N_g-n}}\left[\frac{1}{(h-p)}-\frac{1}{(p+h)}\right]}{(2N_g-n)\left[(h-p)^{\frac{1}{2N_g-n}}+(p+h)^{\frac{1}{2N_g-n}}\right]^2} < 0$$

$$\frac{\partial e_{N_g}}{\partial n} = \frac{2(p+h)^{\frac{1}{2N_g-n}}(h-p)^{\frac{1}{2N_g-n}}}{(2N_g-n)^2\left[(h-p)^{\frac{1}{2N_g-n}}+(p+h)^{\frac{1}{2N_g-n}}\right]^2}\left[Ln(h-p)-Ln(p+h)\right] > 0$$

$$\frac{\partial e_{N_g}}{\partial N_g} = \frac{4(p+h)^{\frac{1}{2N_g-n}}(h-p)^{\frac{1}{2N_g-n}}}{(2N_g-n)^2\left[(h-p)^{\frac{1}{2N_g-n}}+(p+h)^{\frac{1}{2N_g-n}}\right]^2}\left[Ln(p+h)-Ln(h-p)\right] < 0$$

□

A.4 Proof Proposition 4

Proof. Suppose $\widehat{e} \in (0,1)$ and let $\varepsilon \geq 0$ represent the communication's cost. Consider the case where all other agents but i conceal both signals. Let $\mathbb{E}U^1$ represents agent i's expected utility after communicating her signal and $\mathbb{E}U^0$ represents agent i's expected utility after concealing her signal.
Suppose agent i has received $s_i = g$. We need to check the following cases:

- If $e_n > \widehat{e}$, then $\mathbb{E}U^1 = -\varepsilon$ and $\mathbb{E}U^0 = 0$. Therefore, $\phi_g = \phi_b = 0$ is a symmetric Nash Equilibrium in the communication stage.

- If $e_{n-1} \geq \widehat{e} \geq e_n$, then:

$$\mathbb{E}U^1 = \frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^n + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^n}{\left(\frac{1+\widehat{e}}{2}\right)^n + \left(\frac{1-\widehat{e}}{2}\right)^n} - \varepsilon$$

and

$$\mathbb{E}U^0 = \frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^n + \left(\frac{1+\widehat{e}}{2}\right)^n + \left(\frac{1-\widehat{e}}{2}\right)^n}{\left(\frac{1+\widehat{e}}{2}\right)^n + \left(\frac{1-\widehat{e}}{2}\right)^n}$$

Since $\mathbb{E}U^0 = \mathbb{E}U^1 + \varepsilon$, then $\phi_g = \phi_b = 0$ is a symmetric Nash Equilibrium in the communication stage.

- If $\widehat{e} > e_{n-1}$, then:

$$\mathbb{E}U^1 = \frac{(p+h)\left[\left(\frac{1+\widehat{e}}{2}\right) + \beta_2\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1+\widehat{e}}{2}\right) + (p-h)\left[\left(\frac{1-\widehat{e}}{2}\right) + \beta_2\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1-\widehat{e}}{2}\right)}{\left[\left(\frac{1+\widehat{e}}{2}\right) + \beta_2\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1+\widehat{e}}{2}\right) + \left[\left(\frac{1-\widehat{e}}{2}\right) + \beta_2\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1-\widehat{e}}{2}\right)} - \varepsilon$$

and

$$\mathbb{E}U^0 = \frac{(p+h)\left[\left(\frac{1+\widehat{e}}{2}\right) + \beta_1\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1+\widehat{e}}{2}\right) + (p-h)\left[\left(\frac{1-\widehat{e}}{2}\right) + \beta_1\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1-\widehat{e}}{2}\right)}{\left[\left(\frac{1+\widehat{e}}{2}\right) + \beta_1\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1+\widehat{e}}{2}\right) + \left[\left(\frac{1-\widehat{e}}{2}\right) + \beta_1\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1-\widehat{e}}{2}\right)}$$

Since $\beta_2 > \beta_1$, then $\mathbb{E}U^0 > \mathbb{E}U^1 + \varepsilon$. Therefore, $\phi_g = \phi_b = 0$ is a symmetric Nash Equilibrium in the communication stage.

Suppose agent i has received $s_i = b$. We check the following cases:

- If $e_n > \widehat{e}$, then $\mathbb{E}U^1 = -\varepsilon$ and $\mathbb{E}U^0 = 0$. We can conclude that $\phi_g = \phi_b = 0$ is a symmetric Nash Equilibrium in the communication stage.

- If $e_{n-1} > \widehat{e} \geq e_n$, then $\mathbb{E}U^1 = -\varepsilon$ and $\mathbb{E}U^0 = 0$. Then $\phi_g = \phi_b = 0$ is a symmetric Nash Equilibrium in the communication stage.

- If $e_{n-2} \geq \widehat{e} \geq e_{n-1}$, then $\mathbb{E}U^0 = 0$ and

$$\mathbb{E}U^1 = \frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{n-1}\left(\frac{1-\widehat{e}}{2}\right) + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^{n-1}\left(\frac{1+\widehat{e}}{2}\right)}{\left(\frac{1+\widehat{e}}{2}\right)^{n-1}\left(\frac{1-\widehat{e}}{2}\right) + \left(\frac{1-\widehat{e}}{2}\right)^{n-1}\left(\frac{1+\widehat{e}}{2}\right)} - \varepsilon$$

Then $\phi_g = \phi_b = 0$ is a symmetric Nash Equilibrium in the communication stage if:

$$\varepsilon > \frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{n-1}\left(\frac{1-\widehat{e}}{2}\right) + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^{n-1}\left(\frac{1+\widehat{e}}{2}\right)}{\left(\frac{1+\widehat{e}}{2}\right)^{n-1}\left(\frac{1-\widehat{e}}{2}\right) + \left(\frac{1-\widehat{e}}{2}\right)^{n-1}\left(\frac{1+\widehat{e}}{2}\right)}$$

- If $\widehat{e} > e_{n-2}$, then $\mathbb{E}U^0 = 0$ and

$$\mathbb{E}U^1 = \frac{(p+h)\left[\left(\frac{1+\widehat{e}}{2}\right) + \beta_3\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1-\widehat{e}}{2}\right) + (p-h)\left[\left(\frac{1-\widehat{e}}{2}\right) + \beta_3\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1+\widehat{e}}{2}\right)}{\left[\left(\frac{1+\widehat{e}}{2}\right) + \beta_3\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1-\widehat{e}}{2}\right) + \left[\left(\frac{1-\widehat{e}}{2}\right) + \beta_3\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1+\widehat{e}}{2}\right)} - \varepsilon$$

Then $\phi_g = \phi_b = 0$ is a symmetric Nash Equilibrium in the communication stage if:

$$\varepsilon > \frac{(p+h)\left[\left(\frac{1+\widehat{e}}{2}\right) + \beta_3\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1-\widehat{e}}{2}\right) + (p-h)\left[\left(\frac{1-\widehat{e}}{2}\right) + \beta_3\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1+\widehat{e}}{2}\right)}{\left[\left(\frac{1+\widehat{e}}{2}\right) + \beta_3\left(\frac{1-\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1-\widehat{e}}{2}\right) + \left[\left(\frac{1-\widehat{e}}{2}\right) + \beta_3\left(\frac{1+\widehat{e}}{2}\right)\right]^{n-1}\left(\frac{1+\widehat{e}}{2}\right)}$$

□

A.5 Proof Proposition 5

Proof. Suppose $\widehat{e} \in (0,1)$ and let $\varepsilon \geq 0$ represent the communication's cost. Consider the following cases: I) all agents communicate their signal, II) all agents communicate the 'good signal' and conceal the 'bad signal', and III) all agents communicate the 'bad signal' and conceal the 'good signal'.
Suppose agent i deviates, then in each case, agent i can be pivotal in the number of signals needed to vote for Y given a fixed amount of information acquire. Without loss of generality, we characterize the symmetric Nash Equilibriums conditional on the number of 'good signals', because agent i can infer the number of 'bad signals' from the number of 'good signals'.
Let $\mathbb{E}U^1$ represents agent i's expected utility after communicating her signal and $\mathbb{E}U^0$ represents agent i's expected utility after concealing her signal.

Case A: For $e_n \geq \widehat{e}$, agent i is not pivotal

- Suppose agent $j \neq i$ believes that agent i is not communicating signal $s_i = g$.
  If agent i receives $s_i = g$ and is pivotal, then $\mathbb{E}U^0 = 0$ and $\mathbb{E}U^1 = -\varepsilon$.
  If agent i receives $s_i = b$ and is pivotal, then $\mathbb{E}U^0 = 0$ and $\mathbb{E}U^1 = -\varepsilon$.

- Suppose agent $j \neq i$ believes that agent i is not communicating signal $s_i = b$.

If agent i receives $s_i = g$ and is pivotal, then $\mathbb{E}U_i(\widehat{e}, 0) = 0$ and $\mathbb{E}U_i(\widehat{e}, 1) = -\varepsilon$.

If agent i receives $s_i = b$ and is pivotal, then $\mathbb{E}U_i(\widehat{e}, 0) = 0$ and $\mathbb{E}U_i(\widehat{e}, 1) = -\varepsilon$.

Cases I), II) and III)

If agent $j \neq i$ believes that agent i is not communicating signal $s_i = g$, then agent i $\phi_g = 0$ and $\phi_b = 0$.

If agent $j \neq i$ believes that agent i is not communicating signal $s_i = b$, then agent i $\phi_g = 0$ and $\phi_b = 0$.

Therefore, for $e_n \geq \widehat{e}$, $\phi_g = \phi_b = 1$; $\phi_g = 1$ and $\phi_b = 0$; and $\phi_g = 0$ and $\phi_b = 1$ are not symmetric Nash Equilibriums in the communication stage.

Case B: For n odd and $\widehat{e} > e_{\frac{n-1}{2}+1}$, agent i is pivotal in the minimum number of signals

- Suppose agent $j \neq i$ believes that agent i is not communicating signal $s_i = g$.
  If agent i receives $s_i = g$ and is pivotal, then:

$$\mathbb{E}U^0 = \frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}} + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}}{\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}} + \left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}}$$

  and

$$\mathbb{E}U^1 = \frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}} + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}}{\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}} + \left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}} - \varepsilon$$

  If agent i receives $s_i = b$ and is pivotal, then $\mathbb{E}U^1 = -\varepsilon$ and:

$$\mathbb{E}U^0 = \frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1} + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}}{\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1} + \left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n}{2}}}$$

- Suppose agent $j \neq i$ believes that agent i is not communicating signal $s_i = b$.
  If agent i receives $s_i = g$ and is pivotal, then $\mathbb{E}U^0 = 0$ and:

$$\mathbb{E}U^1 = \frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}} + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}}{\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}} + \left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}} - \varepsilon$$

  If agent i receives $s_i = b$ and is pivotal, then $\mathbb{E}U^0 = 0$ and $\mathbb{E}U^1 = -\varepsilon$.

Case I)

If agent $j \neq i$ believes that agent i is not communicating signal $s_i = g$, then agent i $\phi_g = 0$. If agent $j \neq i$ believes that agent i is not communicating signal $s_i = b$, then agent i $\phi_b = 0$. Therefore, for $\widehat{e} > \pi\left(\frac{n}{2}+1\right)$, $\phi_g = \phi_b = 1$ is not a symmetric Nash Equilibrium in the communication stage.

Case II)

If agent $j \neq i$ believes that agent i is not communicating signal $s_i = g$, then agent i $\phi_g = 0$. If agent $j \neq i$ believes that agent i is not communicating signal $s_i = b$, then agent i $\phi_b = 0$ and $\phi_g = 1$ if:

$$\frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}} + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}}{\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}} + \left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}} \geq \varepsilon$$

Therefore, for $\widehat{e} > \pi\left(\frac{n}{2}+1\right)$, $\phi_g = 1$ and $\phi^b = 0$ is a symmetric Nash Equilibrium in the communication stage under the belief on the path if the expected benefit received from communicate is greater or equal than the communication's cost.

Case III)

If agent $j \neq i$ believes that agent i is not communicating signal $s_i = b$, then agent i $\phi_g = 0$. If agent $j \neq i$ believes that agent i is not communicating signal $s_i = g$, then agent i $\phi_g = 0$ and $\phi_b = 1$ if:

$$-\varepsilon \geq \mathbb{E}U^0 = \frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1} + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}}{\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}}\left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}+1} + \left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}}\left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}+1}}$$

Therefore, for $\widehat{e} > e_{\frac{n}{2}+1}$, $\phi_g = 0$ and $\phi_b = 1$ is a symmetric Nash Equilibrium in the communication stage under the belief on the path if the expected negative benefit received from communicate is greater or equal than the communication's cost.

For n even is analogous.

Case C: For n and $e_{\frac{n}{2}+1} \geq \widehat{e} > e_n$ or $e_{\frac{n-1}{2}+1} \geq \widehat{e} > e_n$, agent i is pivotal in N_g

Consider $e_{N_g-1} \geq \widehat{e} > e_{N_g}$, where $N_g - 1 \geq \frac{n}{2} + 1$.

- Suppose agent $j \neq i$ believes that agent i is not communicating signal $s_i = g$.

If agent i receives $s_i = g$ and is pivotal, then:

$$\mathbb{E}U_i^0 = \frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{N_g}\left(\frac{1-\widehat{e}}{2}\right)^{n-N_g} + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^{N_g}\left(\frac{1+\widehat{e}}{2}\right)^{n-N_g}}{\left(\frac{1+\widehat{e}}{2}\right)^{N_g}\left(\frac{1-\widehat{e}}{2}\right)^{n-N_g} + \left(\frac{1-\widehat{e}}{2}\right)^{N_g}\left(\frac{1+\widehat{e}}{2}\right)^{n-N_g}}$$

and

$$\mathbb{E}U^1 = \frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{N_g}\left(\frac{1-\widehat{e}}{2}\right)^{n-N_g} + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^{N_g}\left(\frac{1+\widehat{e}}{2}\right)^{n-N_g}}{\left(\frac{1+\widehat{e}}{2}\right)^{N_g}\left(\frac{1-\widehat{e}}{2}\right)^{n-N_g} + \left(\frac{1-\widehat{e}}{2}\right)^{N_g}\left(\frac{1+\widehat{e}}{2}\right)^{n-N_g}} - \varepsilon$$

If agent i receives $s_i = b$ and is pivotal, then $\mathbb{E}U^1 = -\varepsilon$ and:

$$\mathbb{E}U^0 = \frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{N_g-1}\left(\frac{1-\widehat{e}}{2}\right)^{n+1-N_g} + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^{N_g-1}\left(\frac{1+\widehat{e}}{2}\right)^{n+1-N_g}}{\left(\frac{1+\widehat{e}}{2}\right)^{N_g-1}\left(\frac{1-\widehat{e}}{2}\right)^{n+1-N_g} + \left(\frac{1-\widehat{e}}{2}\right)^{N_g-1}\left(\frac{1+\widehat{e}}{2}\right)^{n+1-N_g}}$$

- Suppose agent $j \neq i$ believes that agent i is not communicating signal $s_i = b$.
  If agent i receives $s_i = g$ and is pivotal, then $\mathbb{E}U^0 = 0$ and:

$$\mathbb{E}U^1 = \frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{N_g}\left(\frac{1-\widehat{e}}{2}\right)^{n-N_g} + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^{N_g}\left(\frac{1+\widehat{e}}{2}\right)^{n-N_g}}{\left(\frac{1+\widehat{e}}{2}\right)^{N_g}\left(\frac{1-\widehat{e}}{2}\right)^{n-N_g} + \left(\frac{1-\widehat{e}}{2}\right)^{N_g}\left(\frac{1+\widehat{e}}{2}\right)^{n-N_g}} - \varepsilon$$

  If agent i receives $s_i = b$ and is pivotal, then $\mathbb{E}U^0 = 0$ and $\mathbb{E}U^1 = -\varepsilon$.

Case I)
If agent $j \neq i$ believes that agent i is not communicating signal $s_i = g$, then agent i $\phi_g = 0$. If agent $j \neq i$ believes that agent i is not communicating signal $s_i = b$, then agent i $\phi_b = 0$. Therefore, for $e_{N_g-1} \geq \widehat{e} > e_{N_g}$, $\phi_g = \phi_b = 1$ is not a symmetric Nash Equilibrium in the communication stage.

Case II)
If agent $j \neq i$ believes that agent i is not communicating signal $s_i = g$, then agent i $\phi_g = 0$. If agent $j \neq i$ believes that agent i is not communicating signal $s_i = b$, then agent i $\phi_b = 0$ and $\phi_g = 1$ if:

$$\frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{N_g}\left(\frac{1-\widehat{e}}{2}\right)^{n-N_g} + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^{N_g}\left(\frac{1+\widehat{e}}{2}\right)^{n-N_g}}{\left(\frac{1+\widehat{e}}{2}\right)^{N_g}\left(\frac{1-\widehat{e}}{2}\right)^{n-N_g} + \left(\frac{1-\widehat{e}}{2}\right)^{N_g}\left(\frac{1+\widehat{e}}{2}\right)^{n-N_g}} \geq \varepsilon$$

Therefore, for $e_{N_g-1} \geq \widehat{e} > e_{N_g}$, $\phi_g = 1$ and $\phi_b = 0$ is a symmetric Nash Equilibrium in the communication stage under the belief on the path if the expected benefit received from communicate is greater or equal than the communication's cost.

Case III)
If agent $j \neq i$ believes that agent i is not communicating signal $s_i = b$, then agent i $\phi_b = 0$.
If agent $j \neq i$ believes that agent i is not communicating signal $s_i = g$, then agent i $\phi_g = 0$ and $\phi_b = 1$ if:

$$-\varepsilon \geq \frac{(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{N_g-1}\left(\frac{1-\widehat{e}}{2}\right)^{n+1-N_g} + (p-h)\left(\frac{1-\widehat{e}}{2}\right)^{N_g-1}\left(\frac{1+\widehat{e}}{2}\right)^{n+1-N_g}}{\left(\frac{1+\widehat{e}}{2}\right)^{N_g-1}\left(\frac{1-\widehat{e}}{2}\right)^{n+1-N_g} + \left(\frac{1-\widehat{e}}{2}\right)^{N_g-1}\left(\frac{1+\widehat{e}}{2}\right)^{n+1-N_g}}$$

Therefore, for $e_{N_g-1} \geq \widehat{e} > e_{N_g}$, $\phi_g = 0$ and $\phi_b = 1$ is a symmetric Nash Equilibrium in the communication stage under the belief on the path if the expected negative benefit received from communicate is greater or equal than the communication's cost.

Consider $e_{N_g-1} > \widehat{e} = e_{N_g}$.

- Suppose agent $j \neq i$ believes that agent i is not communicating signal $s_i = g$.
  If agent i receives $s_i = g$ and is pivotal, then $\mathbb{E}U^0 = 0$ and $\mathbb{E}U^1 = -\varepsilon$.
  If agent i receives $s_i = b$ and is pivotal, then $\mathbb{E}U^0 = 0$ and $\mathbb{E}U^1 = -\varepsilon$.

- Suppose agent $j \neq i$ believes that agent i is not communicating signal $s_i = b$.
  If agent i receives $s_i = g$ and is pivotal, then $\mathbb{E}U^0 = 0$ and $\mathbb{E}U^1 = -\varepsilon$.
  If agent i receives $s_i = b$ and is pivotal, then $\mathbb{E}U^0 = 0$ and $\mathbb{E}U^1 = -\varepsilon$.

Cases I), II) and III)
If agent $j \neq i$ believes that agent i is not communicating signal $s_i = g$, then agent i $\phi_g = 0$ and $\phi_b = 0$.
If agent $j \neq i$ believes that agent i is not communicating signal $s_i = b$, then agent i $\phi_g = 0$ and $\phi_b = 0$.
Therefore, for $e_{N_g-1} > \widehat{e} = e_{N_g}$, $\phi_g = \phi^b = 1$; $\phi_g = 1$ and $\phi_b = 0$; and $\phi_g = 0$ and $\phi^b = 1$ are not symmetric Nash Equilibriums in the communication stage. $\square$

A.6 Proof Proposition 6

Proof. Consider Proposition 4 and 5. In the *Full Non-Disclosure* case, the expected utility is given by:

$$G(e_i) = \begin{cases} -C(e_i) & \text{if } e_n > e_i \\ \\ \frac{1}{2}(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{n-1}\left(\frac{1+e_i}{2}\right) + \frac{1}{2}(p-h)\left(\frac{1-\widehat{e}}{2}\right)^{n-1}\left(\frac{1-e_i}{2}\right) - C(e_i) & \text{if } e_{n-1} > e_i \geq e_n \end{cases}$$

Suppose $C'(0) > 0$, then it is easy to see that for $e_n > e_i$ the optimal level of effort is zero. In the other hand, if $e_{n-1} > e_i \geq e_n$ and the solution is interior, the optimal level of effort e_i^* solves:

$$\frac{1}{4}(p+h)\left(\frac{1+\widehat{e}}{2}\right)^{n-1} - \frac{1}{4}(p-h)\left(\frac{1-\widehat{e}}{2}\right)^{n-1} = C'(e_i)$$

The global optimum will depend on the parameters and the cost's function.
Now, suppose n goes to infinity. Then, the expected benefit received from the implementation of the projects goes to zero. If $C'(0) > 0$, then for some n the optimal solution is zero. On the contrary, if $C'(0) = 0$ agents will acquire information.
In the *Full Disclosure* and *Partially Disclosure* cases, the analysis is equivalente and if the solution is interior, the optimal level of effort e_i^* solves:

$$\frac{1}{2}\binom{n-1}{\frac{n-1}{2}} h \left(\frac{1+\widehat{e}}{2}\right)^{\frac{n-1}{2}} \left(\frac{1-\widehat{e}}{2}\right)^{\frac{n-1}{2}} = C'(e_i)$$

It is easy to check that the solutions are unique, since both functions are strictly concave. □

A.7 Proof Proposition 7

Consider Proposition 6. The expect utility under *Full Non-Disclosure* converges to zero as $\frac{1}{2^{n-1}}$ and the expected utility under any form of communication converges to zero a $\frac{1}{\sqrt{\pi(n-1)}}$.
It is easy to see, that:

$$Lim_{n\to\infty} n \left[\frac{1}{\sqrt{\pi(n-1)}} - \frac{1}{2^{n-1}}\right]$$

Converges to $+\infty$, then the expected benefit received from the project goes to zero faster under *Full Non-Disclosure* than under *Full Disclosure*, *Partially Disclosure-g* and *Partially Disclosure-b*.

A.8 Proof Corollary 1 and Corollary 2

Proof. Corollary 1, directly from Preposition 4. Corollary 2, directly from Preposition 5. □