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Homogeneity vs. Heterogeneity in Collaborative Decision-Making:

A Theoretical Model on Specialisation in Committees

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Abstract

Diversity in teams is an advocated subject as it would reduce free riding and result in better decision-making. This paper analyses differences in decision efficiency and quality between homogeneous and heterogeneous committees under different voting rules. I employ a sequential model where committee members can acquire endogenous information about a project with an unknown profitability before voting on its implementation. I find that members in a homogeneous committee vote uninformed, independent of the voting rule. In a heterogeneous committee the voting rule determines which type of committee member is pivotal and acquires information. A majority voting rule results in a range of projects to be implemented while a unanimity voting rule allows only highly profitable projects to be implemented. Furthermore, committee size is negatively related with information acquisition in equilibrium. This paper contributes to the theoretical literature on team and committee strategic decision making by describing the influence of the composition of the team and the selected voting rule on information acquisition and project implementation.

Keywords: Committee decision-making, Information acquisition, Specialisation, Heterogeneity.

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1 Introduction

Collaborative decision-making is one of the vital aspects of managing an organisation. Many decisions on policies or investments are made by committees, both in governing and non-governing institutions. Government institutions such as the U.S. Senate, which performs its tasks using 24 committees each of which divide their work among numerous subcommittees, and the European commission, which role is to devise and execute E.U. policy, divide their tasks over several teams. In business, boards of directors are advised by several specialised committees, and in court, sentences are often based on the jury committee's verdict. The reason for assembling different committees of experts to make decisions is the increased rationality of the decision made by a group compared to an individual (Charness and Sutter, 2012). Making decisions in collaboration creates value due to the larger range of alternative understandings on the subjects (Owen, 2015). As organisations start to recognise the benefits of teams consisting of people with different opinions, backgrounds, gender, etcetera, the composition of the teams becomes more and more important.

In the theoretical literature on collaborative decision-making, the *free riding* problem is broadly recognised. Gersbach (1995) is one of the first to describe the free riding problem in committee decision-making. In a setting where the committee members need to vote on a project after acquiring costly information, free riding could pose a significant problem. When individual members are utility maximising, their level of effort to acquire information is generally different from the optimal level of information acquisition needed to make the correct decision. As they incur costs by providing effort, they are incentivised to put in the least amount of effort possible.

In this paper, I study a strategic setting where the composition of committees affects the decision-making process of the committee in terms of information acquisition. I make a distinction between a committee with members that have a similar *expertise* and a committee where the members differ in their expertise, the homogeneous and the heterogeneous committee respectively. This difference in expertise within the committee can be caused by several factors such as the member's background or interests which has led them to cover different positions or functions within the committee. I define the members' expertise as a personal investment in the project because each expert differs in his opinion on the perceived value of the project. This results in preference heterogeneity. When a committee is homogeneous, the members all have the same level of personal investment. In the remainder of this paper I switch back and forth between the member's 'personal investment' and 'type'.

To research the difference between these two types of committees, I propose a model in the field of game theory and a mathematical analysis on the strategic behaviour of the committee members. This analysis answers the questions how the composition of a committee influences the *efficiency* of the decision-making process and the *quality* of the decision in a strategic setting with endogenous information. Efficiency of the decision-making process is defined as the total amount of information collected by a committee, and how results in a decision. Assuming concave returns on information acquisition, a decision based on more members acquiring information is more efficient than the decision made on the same amount of information acquisition of one member. However, in some settings it is not efficient for all agents to acquire information as the impact of each member's vote is not equal due to the distribution of types. Furthermore, I define the quality of the decision as the amount of information that was acquired before making the decision, and how this influenced the type of project implemented. The type of the agent that acquires information, and the voting rule, can have quality implications on the outcome of the vote as they influence the type of the implemented projects. This means that efficiency and quality are intertwined; a higher amount of information acquisition leads to a higher quality decision, but information acquisition by all agents is not always efficient due to concave returns on information acquisition and agents' types. Additionally, I analyse both committee types employing a different voting rule. I describe how two voting rules, a simple majority and a unanimity voting rule, influence the amount of free riding within the committee and the type of projects that are implemented.

A large share of the theoretical literature on committee decision-making employ models with homogeneous agents for their analysis.[1] Teams consist of different people and these people have different skills, therefore the assumption of agents having the same characteristics could influence the applicability of these results on real situations. I aim to fill the gap between the theoretical literature on committee decision-making with homogeneous agents, and more real situations where these teams consist of different experts with varying abilities and preferences.

I employ a sequential model where agents first need to decide on the (costly) acquisition of endogenous information after which they obtain a signal about the payoff of the project. Knowing the signal, the agents then have to vote on the implementation of the project. For the information acquisition component, I follow Bijkerk et al. (2018). Their way modelling this component allows for a discreet and boundless measure of information acquisition. I solve the model using a Perfect Bayesian Equilibrium concept.

As the majority voting rule is very common amongst committees, I start my analysis using this rule. Jung and Mongelli (2016) describe the role of costly information in monetary policy decision-

[1] Examples are research done by Fedderson and Pesendorfer (1998), Persico (2004), Gerardi and Yariv (2008a), and Gershkov and Szentes (2009).

making and argue that the voting rule is a means of risk management in monetary policy committees. A committee consisting of multiple members with different views help the policy makers to hedge against uncertainty. By employing the right voting rule, these different views can be combined in an efficient manner and allow the committee to be decisive. As the majority voting rule causes the median voter to be pivotal, it could benefit the committee to employ different voting rules for different compositions and tasks of the committee. After providing an analysis using a simple majority voting rule, I will elaborate on the unanimity voting rule.

First, I analyse under which circumstances an agent will acquire information. Only when agents are pivotal, they might acquire information. An agent is pivotal when this agent's vote determines the outcome of the vote. This is the same as if only one agent would decide on the implementation of a project without a committee. Second, the amount of information acquisition under the assumption that the agent has the pivotal vote is described. The optimal amount of information acquisition decreases with the agent's level of personal investment and with information acquisition costs. This result is in line with the expectations of the model. Intuitively, as personal investment rises, the expected returns on the project decrease. Furthermore, when information is more expensive, the agent will be more dependent on the level of his personal investment to decide on the implementation of the project.

In a homogeneous committee employing a majority voting rule, the agents are never pivotal. This causes the agents to deviate from a pure strategy in which they acquire information to a pure strategy equilibrium in which none of the agents acquires information. The agents know they are part of a homogeneous committee; therefore, their utility maximising strategy is to acquire no information and vote only based on their type. Changing the voting rule to a unanimity voting rule does not change the equilibrium, however, it does change the reason why agents do not acquire information in equilibrium. In a committee employing a unanimity voting rule, the agents can have the pivotal vote for certain types. They decide not to acquire information as they know that the other agents will ensure the right project is implemented. In this case, free riding is the reason that there is no information acquisition in equilibrium. The lack of information acquisition in equilibrium causes the committee to forgo some profitable projects and implement some unprofitable projects. Allowing mixed strategies, the agents *do* acquire information the utility optimising amount of information with a probability dependent on a combination of the costs and the agents' personal investment. However, this only occurs when the agents' personal investment is close to the average personal investment. Regarding mixed strategies, the voting rule influences the equilibrium outcome only in a minor way as under a unanimity voting rule the probability that an agent is pivotal is slightly larger than under a majority voting rule.

The results on the decision-making process of a heterogeneous committee depend highly on the voting rule. If pivotal, the agent will acquire information as if he is the only decision-maker and vote accordingly. However, employing a majority voting rule, an agent only has the pivotal vote when he is of the median type. For the unanimity voting rule this occurs when the agent is of the highest type. The probability that an agent is of that specific type is largely dependent on the committee size; a larger committee reduces the probability of the agent being pivotal. Due to the agents having different types, free riding is not possible in the heterogeneous committee. The reason why agents would choose not to acquire information is that they are often not pivotal in determining the outcome of the vote and therefore acquiring information would not increase their utility.

These findings imply that heterogeneous committees make informed decisions while homogeneous committees vote uninformed. Heterogeneity in committee decision-making cannot induce information acquisition in all agents, but it can help to decrease free riding and increase total information acquisition compared to a homogeneous committee. As I employ a quadratic utility function, informed voting under a unanimity rule results in implementation of only highly profitable projects. This could be an advantage as resources are generally scarce and therefore it is efficient to allocate them only to projects with a high profitability. On the downside, the committee could decide not to implement projects that have positive return just because there is a single agent with a high personal investment in the project and 'dislikes' the project from his expert point of view. Dependent on the goals of the committee, the voting rule and the composition should be considered carefully in order to achieve efficient decision-making.

A direct application of these findings can be on political committees such as the European Commission. This committee needs to decide on the implementation of new programmes and laws or the allocation of budgets. These projects have continuous but distinct payoffs and potentially a binary choice of implementation. Furthermore, the composition of the appointed committee has a large influence on the realisation and acquisition of projects; as the members are responsible for an appointed subject, plus the fact that they come from different countries across the European Union, their preferences following from their expertise differ throughout the committee. Another application can be on executive committees such as hiring committees for firms. Similar to the European Commission, this type of committee makes decision following the parameters in this model; payoff is continuous, there is a binary choice of implementation and the committee members often have different positions (expertise) in the decision-making process.

This paper proceeds as follows. Section 2 discusses literature related to team decision-making. Section 3 describes the model and the equilibrium concept. Following the model, Section 4 presents the analysis on the information acquisition and voting equilibria in a homogeneous and heterogeneous committee under different voting rules. Section 5 provides a discussion on the results. Mathematical analyses of the propositions can be found in the appendix in Section 7.

2 Related literature

A committee is a team. Team decision-making is a largely covered subject, which includes decision-making literature on committees, board of directors, juries, and panels. My model analyses the effect of the committee's composition on the amount of information acquired and the quality of the decisions made by the committee. The insights provided in this model could be valuable in the mentioned subjects where a team needs to vote on a project with an uncertain payoff after acquiring costly information. Therefore, I attempt to include a broad range of insights from the literature on team decision-making and not limit the related literature to only committee decision-making. This section is divided in three subjects: (1) team composition, (2) jury decision-making, and (3) mechanism design.

The larger share of the literature on this subject is theoretical of nature. A reason brought forward for the small amount of empirical research on the subject is that an empirical analysis on the composition of the team and the quality of the decisions can be flawed through endogeneity problems (Demsetz and Lehn, 1985; Hermalin and Weisbach, 2003). Besides, it is difficult to assess the quality of a decision as the potential consequences of a different decision are impossible to measure, hence it is a challenge to collect data on decision quality.

2.1 Team composition

The most recent literature directly related to this paper are Bhattacharya et al. (2018), Chan et al. (2018), and Zhao (2018), which all study the impact of heterogeneous preferences on decision quality. Bhattacharya et al. (2018) elaborates on the composition of panels of experts based on the expert's preferences. In a persuasion game where the expert's type indicates how informed the expert is, they find that better decisions are made by a panel of experts with diverse preferences when the correlation between the expert's types is high. When the correlation between the types is low, i.e. one expert is informed and the other is not, the decision quality is increased by employing a panel of experts with identical preferences. The current paper focusses on acquiring information, rather than being informed and persuade, by using both a non-binary payoff for the agents and non-binary information acquisition.

Zhao (2018) studies agent's preferences and the optimal voting rule in committees with endogenous information acquisition. Depending on the voting rule, the committee members acquire more information if their preferences are more polarised. Similar to this paper, Chan et al. (2018) study the effect of agent's preferences and the voting rule on the accuracy of the decisions and find that diverse preferences lead to a higher accuracy of the decision. Both papers differ to the current paper as they focus more on the voting rule and less on information acquisition. However, these papers indicate that in a strategic setting, employing a team that consists of members with heterogeneous preferences could result in better decisions.

Using a model with information collecting committee members and a decision maker, Beniers and Swank (2004) argue that preference alignment between the members and the decision maker allows for efficient information collection when the costs of information are low. Furthermore, when costs are high, the committee should consist of members with heterogeneous preferences. The intuition behind this result is that a member with an outlying preference has a larger incentive to collect information and therefore is willing to incur higher costs. As is clear in my analysis, composing the committee with homogeneous members induces lower information acquisition than when it consists of heterogeneous members, which is in line with the results of Beniers and Swank (2004).

The empirical literature on the composition of teams and the quality of their decisions is largely focused on the performance of boards of directors. Important is that the definition of board composition throughout this literature is different from the definition used in this paper; board composition is often measured by board independence or by the amount of inside and outside directors. In this paper, team composition is defined based on the preferences of the team members. However, the results from the literature on boards of directors are insightful and allows for this paper to be put in the right perspective.

The empirical literature on board composition is surveyed by Hermalin and Weisbach (2003). One of their findings is that there has not been found a relationship between board composition and financial performance in the empirical literature. As mentioned, their reason for this finding in the literature is that the composition of the board possibly is not exogenously determined. Addressing the endogeneity issue by employing a simultaneous equations system, Drakos and Bekiris (2010) find that board composition does not affect the performance of the firm using data on firms listed at the Athens Stock Exchange from 2000 to 2006. Contradictory to these findings is the survey on the literature by Adams et al. (2010) that suggest that boards used to be more passive, serving as an advisory or counselling source and only act in crisis situations, but that more recent research indicates that boards have become more active and independent monitors over time. This implies that the relationship between board composition and financial performance could have changed over time.

One of few theoretical works on the subject of board composition and the board's effectiveness in monitoring firms is that of Raheja (2005). She employs a different method and focuses more on the characteristics of both the firm and the board members individually. She finds that the optimal board structure does have an impact on the effectiveness of the board; firms in which it is easier for outsiders to verify projects should employ more outside directors on the board, and in firms where this is difficult a larger share of inside directors on the board is preferred.

2.1.1 Specialisation

Related to this paper are the insights of the literature on specialisation in team decision-making. Bolton and Dewatripont (1994) propose a model in which agents need to process information, rather than making decisions, and can specialise after repeatedly processing a specific type of information. They find that specialisation will increase the amount of information that can be processed if the benefits from of the processed information outweighs the increase in the costs of communication. In a non-strategic, information aggregation model using homogenous agents with a common goal, Ben-Yashar et al. (2012) describe decision quality that depends on the total aggregation of information. They find that, dependent on the aggregation rule, in some cases specialisation is preferred over non-specialisation, and vice-versa. If the non-specialised decision makers make optimal decisions, specialisation is inferior to non-specialisation.

2.1.2 Size

Committee size is an important aspect in the literature on team decision-making as size is directly related to the free rider problem. The application of the free rider problem in the literature on board of directors' decision-making is explained by Adams et al. (2010). They point out the difference between the free rider problem applied on board of directors and on team decision-making; in boards, total effort of the board is important while in team decision-making, individual effort is often of high importance. Furthermore, they argue that total equilibrium effort depends highly on assumptions, which makes it difficult to apply these insights on boards of directors. The empirical paper by Yermack (1996) explains that in large U.S. corporations, smaller boards of directors (five to seven board members appears to be optimal) are associated with higher firm value, profitability, operating efficiency, and CEO performance incentives. This finding also applies to small firms, as found by Eisenberg et al. (1998). Contrary, Coles et al. (2008) find evidence that the size of the board should depend on the type of firm; in association with firm value, more complex firms need larger boards. Drakos and Bekiris (2010) find that board size and firm performance are negatively related.

More specifically on committee decision-making, employing a model with heterogeneous preferences and costly participation in the voting process, Cai (2009) finds that the optimal committee size is increasing with the degree of the heterogeneity of the agents' preferences. Adding communication, Hahn (2017) shows that experts are more reluctant to speak in larger committees, which could result in a lesser committee performance. Li (2001) argues that the amount of free riding is higher in a larger committee, both in hiring committees as well as in juries. These results are in line with my findings as an increase in committee size induces lower information acquisition per agent due to a smaller impact on the outcome of the vote.

2.2 Jury

A large part of the literature on collaborative-decision making has been done in the field of jury decision-making. The quality of the decision is determined by a binary variable: guilty, or not guilty. (Gerardi and Yariv, 2002, 2008a, and 2008b; and Persico, 2004). This binary variable allows for a clear definition of decision quality. In a model with homogeneous jurors, Fedderson and Pesendorfer (1998) address the importance of the decision rule on the decision outcome: increasing with jury size, the unanimity rule increases the chance of convicting an innocent suspect under strategic voting. Persico (2004) elaborates further on this subject by including endogenous information acquisition and finds that the unanimity vote can only be optimal if the information that is available is accurate. In this paper the agents choose the accuracy of their signal by investing in the acquisition of information. This allows for more dynamic information acquisition in comparison to the other papers. These papers indicate that decision quality in juries is highly dependent on not only the voting rule, but also on the accuracy of the available information.

2.2.1 Size

The base of a large share of jury decision-making literature is the Condorcet's jury theorem; the larger the group, the more likely the correct decision is made (e.g. Young, 1988; Austen-Smith and Banks, 1996; Ben-Yashar and Nitzan, 2014). However, most of the literature on juries does not incorporate endogenous information acquisition which could lead to the free rider problem. Mukhopadhaya (2003) shows that in symmetric mixed-strategy equilibria with costly information, a smaller jury makes better decisions compared to a larger jury because the incentive to free ride increases with the size of the jury. However, jury size does not matter in asymmetric pure-strategy equilibria. These insights are in line with the literature on committee size as described in Section 2.1.2.

2.3 Mechanism design

Another well represented part in the literature on team decision-making is the research on mechanism design in team decision-making. This research involves how the decision-making process in teams or organisations should be structured for efficient information utilisation. Li (2001) addresses the notion of conservatism, also described as the status quo bias. By employing a decision rule that is more conservative than the ex post efficient decision rule, the committee is more inclined to concede with their priors when the acquired information is not dominant towards the alternative project. However, applying a conservative decision rule increases the incentives of the committee members to acquire information and increases the decision quality, improving ex ante efficiency.

2.3.1 Incentive compatibility

Research on incentive compatibility provides notable insights on the efficiency of information aggregation. Gershkov and Szentes (2009) consider the revelation principle in an endogenous information model with sequential extraction of information to analyse the optimal mechanism for both the collection and aggregation of information. They find that the optimal mechanism in a committee with homogeneous agents is sequential and approaches each agent randomly to acquire information and report the signal. In this setting it is beneficial for the agents to acquire information and correctly report the signal. They argue that the efficiency of this mechanism holds for agents with heterogeneous costs of information collection, however, the sequence in which the agents are approached should be altered. The agents with the lowest costs are placed at the beginning of the sequence at a higher frequency. Nonetheless they note that there are difficulties analysing this assumption in this setting as the incentive compatibility constraint differs when the sequence of the agents is altered.

The optimal incentive mechanism for the mechanism designer to induce homogeneous agents to acquire information is studied by Gerardi and Yariv (2008a). They find that ex ante optimal mechanisms could be ex post inefficient; not all information that is acquired is exploited in making the decision. Furthermore, they describe how the ex post efficient mechanism depends on the precision of the information as well as on the precision's relationship with the costs of acquiring information and the number of agents. This is in line with a second finding of Gershkov and Szentes (2009). They discuss that an ex ante optimal mechanism which is ex post efficient is restricted by the precision of the signal and by the costs of acquiring information.

Analysing the free rider problem in multi-agent computations, Smorodinsky and Tennenholtz (2006) propose a model in which a group of agents need to compute a binary parameter. Each agent has his own secret and can choose to compute the secret and report it to jointly arrive at the correct binary value. The free rider problem affects the outcome because the agent needs to incur costs to compute his secret. They find that by employing a sequential information extraction mechanism, the incentive for the agents to compute their signal increases because it increases the impact of the computation of their secret on the joint computation. This finding indicates that the design of the mechanism, or information extraction design, plays a significant role in reducing the amount of free riding in group decision processes. Furthermore, in line with this paper, the probability that the agent's vote is pivotal has a large impact on the amount of effort induced by the mechanism designer.

2.3.2 Decentralisation

Decentralisation and task separation can be used to diminish the free rider problem in team decision-making. Aghion and Tirole (1997) argue that delegation of authority from the principal to the agent incentivises the agent to acquire relevant information but incurs costs to the principal as she loses control over the decision. They explain this trade-off to be beneficial for the principal under a number of circumstances. Despite the fact that this is not a study on team decision-making, these insights could be applied in a team setting. When each agent is directly responsible for its own decision, the free-rider problem should become less strong and overall information acquisition should increase.

In the current paper, the agents acquire information on one project. However, by using agents with heterogeneous preferences, each agent has a different potential payoff which implies a different incentive. This increases the responsibility for the agent's individual payoff. Schulte and Grüner (2007) use Radner's (1993) framework to set up a model in which the quality of the decision is determined by the payoff of an investment project that was chosen from a set of competing investment opportunities. In a later paper using the same framework (Grüner and Schulte, 2010), the authors define the decision quality as the accuracy of a guess for a sum of binary variables. They argue that aggregating the same information causes a great incentive to free ride, and that dividing tasks among agents leads to less free riding. They propose a model in which information is aggregated by performing concrete tasks, which need to be completed in order to gain insights in the state of the world that is relevant for the decision. They find that decentralizing the tasks that need to be completed in order to acquire perfect information increase the speed and quality of collective decision-making.

2.3.3 Persuasion

Communication and persuasion literature present insights on the incentives of team members to not only acquire information but disclose it with others as well. Bijkerk et al. (2018) study the effects of several communication motives on information acquisition and decision quality in a firm decision-making model. According to Bijkerk et al. (2018), the executive who acquires information is incentivised to exaggerate the project or the firm value to outsiders due to the persuasion and impression motives. This leads to a decrease in information acquisition as the executive can only overstate value whilst reporting truthfully when his information is less accurate.

Che and Kartik (2009) model opinion differences between an advisor, which acquires information, and a decision maker. They find that a difference in opinion induces effort of the advisor to acquire information but decreases the amount of information he chooses to disclose with the decision maker. However, the decision maker is better off employing an advisor with a contrasting opinion as the total amount of information communicated is higher, because a homogeneous advisor would acquire less information. Van den Steen (2010) and Hirsch (2016) find similar results modelling the same problem in corporate and political organisations. This illustrates that the mechanism through which preference heterogeneity causes higher information acquisition is not limited to project payoff but could also be based on communication motives.

2.3.4 Transparency

Transparent decision-making is another mechanism design to possibly induce effort within the team. Cornelli et al. (2013) find empirical evidence for an increase in information acquisition by a board of directors when they are enabled to monitor and replace their CEO more easily. Gersbach and Hahn (2012) use a two-period principal agent model using agents that are heterogeneous in their ability of acquiring correct information. They find that transparency of the behaviour of committee members is in most cases beneficial for the principal, but it makes the agents worse off as they have to increase their effort in information acquisition. On the other hand, Visser and Swank (2007) argue that reputation is influential in the behaviour of committee members, which could be magnified by transparency and lead to biased decisions.

Using committee members with career concerns in a two-period model, Levy (2007) finds that a committee has a higher probability to accept proposals that do not comply with the priors of the members when the decision-making process is transparent. The reason for this is that when the process is transparent, the proposal does not comply with the members prior biases either. However, this depends largely on the voting rule and therefore does not hold for all environments due to the tendency of career-chasing members to vote against the status quo. These findings could indicate that there are gains in decision quality when the decision-making process is transparent. Nonetheless, Bijkerk et al. (2018) apply their insights of the effects of the persuasion motive on information acquisition on the notion of transparent communication between the executive and insiders of the firm. They find that transparency afflicts the executive with the persuasion motive which leads to an increase in communication costs and with that a loss in information efficiency. This could indicate that the benefits of transparency are highly dependent on the environment and could either have a positive or negative influence on both the decision quality and decision efficiency.

3 Model

I consider a two-period model where a committee must decide on the implementation of a project. In the first period, the committee members individually choose on their investment in the acquisition of private information about the payoff of the project. In the second period, they need to vote together on the implementation of the project.

A committee of $n \in \mathbb{N}$ agents jointly decides on the implementation of a project after each agent individually has acquired information.[2] Consider an organisation with a project with profitability $\alpha \sim U(0,1)$. Nature decides on the profitability parameter α, and this parameter is equal for all agents. The investment can be different for each agent $i \in \{1, \dots, n\}$ and equal to $\beta_i \sim U(0,1)$. Each agent knows its own type β_i, and this is private knowledge. The investment differs amongst heterogeneous agents as every agent has a personal preference for the implementation of the project. The payoff of the project for agent i is therefore distributed over the interval $(\alpha - \beta_i) \in [-1,1]$.[3]

The agents know their type β_i before they collect information. In this setting, the type of information collection as proposed by Bijkerk et al. (2018) is useful to analyse the differences between a homogeneous and heterogeneous committee. It enables the agents to adapt the accuracy of their signal to their type β_i. Following Bijkerk et al. (2018), each agent i needs to decide on the amount of information acquisition $q_i \in \mathbb{N}$. The information collection parameter q_i represents the effort the agent exerts to collect information. It determines the accuracy of the signal the agent will obtain; if the agent chooses q_i, he learns signal $s_i \in \{1,2, \dots q_i\}$. The signal s_i shows the subinterval of the project's profitability $\alpha \in \left[\frac{s_i - 1}{q_i}, \frac{s_i}{q_i}\right]$. After learning α, the agent knows his payoff of the project and can vote accordingly. Parameter q_i is private knowledge.

[2] For simplicity, I assume that the committee consists of an uneven number of agents.
[3] Note that this is not the same as the utility of agent i, which is described later in this section. The payoff of the project determines whether the project yields a positive or a negative utility for the agent and, in turn, if the agent votes in favour or against the project.

Collecting information is costly as the agent needs to exert effort; the costs of collecting information is given by $c(q_i)$. These costs are assumed to be equal across agents.[4] After observing the signal s_i, agent i's expectation on the project's payoff is given by

$$E[\alpha - \beta_i | s_i] = \frac{2s_i - 1}{2q_i} - \beta_i. \quad (1)$$

Given this signal, each agent votes publicly on the implementation of the project $v_i \in \{0,1\}$. I consider two decision rules; (1) a simple majority voting rule, and (2) a unanimity voting rule. Using the simple majority rule, the project will be implemented when more than half the agents vote in favour, $\sum_i v_i > \left(\frac{1}{2}\right) n$. The probability of the implementation of the project is denoted by

$$p = \Pr\left[\sum_i v_i > \left(\frac{1}{2}\right) n\right]. \quad (2)$$

Employing a unanimity voting rule, the project will only be implemented when all the agents vote in favour, $\sum_i v_i = n$. This gives the following probability of implementation

$$p = \Pr[\sum_i v_i = n]. \quad (3)$$

Based on the literature on information acquisition (examples are Szkup and Trevino, 2019; Bikhchandani and Obara, 2017) I assume the cost function $c(q_i)$ is increasing and linear in q_i.The cost function is defined as $c(q_i) = C(q_i - 1)$ with c as a cost scaling parameter. Given the cost function, the utility function $U_i(q_i)$ is increasing and concave in q_i. The ex-ante utility function of agent i is the defined as

$$U_i(q_i) = p(\alpha - \beta_i)(\alpha + \beta_i) - c(q_i). \quad (4)$$

I have chosen for this type of utility function as it is increasing and convex in the project profitability α and decreasing and convex in the agent's personal investment β_i. For projects with a positive payoff, that is when $\alpha > \beta_i$, this leads to a preference for larger projects.[5] Note that a marginal increase in q_i has a decreasing impact on the precision, and therefore the benefits of an increase in q_i are declining; the utility function is concave in the benefits of q_i. The timeline of this model is as follows:

<u>Period one:</u>

- Nature determines the agent's type $\beta_i \in [0,1]$.
- Investment project arises, nature determines its value $\alpha \in [0,1]$.
- Agents chooses their investment in information acquisition $q_i \in \mathbb{N}$ on the project's value α.

[4] They are observing the signal from their own perspective. The cost is the effort put in to obtain this signal.
[5] This type of utility function is realistic as the literature on agency theory suggest there is a tendency for 'empire-building' when decision makers implement projects (see Jensen, 1986; Masulis et al., 2007; Hope and Thomas, 2008).

- Agents receive a private signal $s_i \in \{1,2, \dots q_i\}$ about the value of the project α.

Period two:

- Agents vote simultaneously on the implementation of the project $v_i \in \{0,1\}$.
- Project is implemented if the sum of votes meets the voting rule.
- Payoffs are realised.

I solve this model for Perfect Bayesian Equilibria (PBE). A PBE consists of the information acquisition q_i^* and the voting strategy v_i that maximises agent i's utility function as given by Equation (4) and is therefore written as (q_i^*, v_i^*).

The main goal of this paper is to find the difference in the quality and efficiency of the decision between homogeneous and heterogeneous teams. I analyse the equilibrium strategies in three cases; a single person committee in which an agent is always *pivotal,* a committee with homogeneous agents and a committee with heterogeneous agents. In the homogeneous case, the agents all have the same type and therefore have the same investment $\{\beta_1 = \cdots = \beta_i = \cdots = \beta_n\}$ and in the heterogeneous case, the agents have different types and therefore have a different investment $\{\beta_1 \neq \cdots \neq \beta_i \neq \cdots \neq \beta_n\}$. I analyse how much information the agents collect, how they vote, and when they implement the project in each setting.

In summary, the agent knows whether the committee is homogeneous or heterogeneous, this is public information. Also, the agent knows his own type β_i, which is private information. The agent decides on the information collection parameter q_i to obtain signal s_i and learn about the value of the project α. Combining the information about the project value α with the agent's type β_i, the agent votes on the implementation of the project $v_i \in \{0,1\}$.

When the agent decides not to acquire information and stay uninformed, he will vote based only on his type β_i. The expected value of the project $\alpha \sim U(0,1)$ before having received a signal is given by

$$E[\alpha] = 0.5 \tag{5}$$

Assuming the agent has the pivotal vote, the agent only votes $v_i = 1$ when he expects a positive payoff. This is only the case when $E[\alpha] > \beta_i$. Substitute this in Equation (5) to find the uninformed vote

$$(q_i^*, v_i^*) = \begin{cases} (1,1), if\ \beta_i < 0.5 \\ (1,0), if\ \beta_i > 0.5 \end{cases}. \tag{6}$$

I will refer to Equation (6) as the 'uninformed vote'.

4 Analysis

To analyse the model and its equilibria, I use backward induction. In period two, each agent needs to decide on his vote on the implementation of the project given the information obtained in period one. The vote is therefore dependent on the agents' choices in period one. By using backwards induction, the choice in period one can be determined based on the payoffs of this choice in period two. I start by discussing the circumstance in which an agent will acquire information followed by the optimal amount of information acquisition in that situation. After that, I will analyse the homogeneous committee, followed by the heterogeneous committee. Lastly, I will discuss *when* voters are pivotal under different voting rules and how the number of agents influences information acquisition.

4.1 Pivotal vote

The first insight in the model that is important for understanding the strategic actions of the agents in different setting is that an agent will *only* acquire information if he thinks his vote is *pivotal.* That is, when the agent's vote is the vote that determines whether the project is implemented. The intuition is that when an agent knows he is not pivotal, he will have no influence on whether the project is implemented or not and therefore obtains a strictly higher utility by not exerting effort to acquire information and vote according to the uninformed vote described in the end of Section 3. Proposition 1 describes the requirement for an agent to exert effort to acquire information.

Proposition 1 *Agents do not acquire information when they know they are not pivotal.*

When the agent thinks he is pivotal, he will acquire information as if the committee only consists of one person. The agent's vote is always pivotal in a one-person committee as there is only one person to decide on the implementation of the project. I will first summarise how the equilibrium values are analysed before I move forward to the mathematical analysis.

Using backwards induction, the analysis starts in period two. To retrieve the optimal level of information collection, the agent determines the expected utility of his vote given the signal, and he needs to know the probability that this specific vote occurs. First, calculate the expected utility the agent will obtain from voting in favour of the project $v_i = 1$ or against the project $v_i = 0$ given his level of information acquisition q_i and the signal he received s_i. Second, calculate the probability that $v_i = 1$ or $v_i = 0$ is voted by the agent. Third, by combining the first two steps, the agent obtains the expected utility *before* voting, given the amount of information acquisition q_i and the signal s_i.

Moving to period one, the agent needs to know the utility he expects to acquire for any amount of information collection, which can then be maximised to find the optimal level of information acquisition. The fourth step is to calculate the expected utility *before* learning the signal s_i, but *after* choosing q_i. This is the sum of the expected utilities that accompany the possible signals given the level of information acquisition, $s_i \in \{1,2,\dots,q_i\}$, divided by the amount of information acquisition q_i. This gives the expected utility of choosing a specific q_i. The last step is then to optimise this expected utility to find the optimal value of the information collection parameter q_i^*. Following these steps, Proposition 2 describes the amount of information acquisition q_i^* and the voting behaviour v_i^* for the agent's type β_i, the costs of acquiring information C, and the received signal s_i in equilibrium.

Proposition 2 *When agent i has the pivotal vote, there exists a pure strategy Perfect Bayesian Equilibrium (q_i^*, v_i^*) that maximises the utility of agent i as given by Equation (4). The pure strategy PBE is described by*

$$(q_i^*, v_i^*) = \begin{cases} \left(\left[\frac{1-\beta_i}{6C}\right]^{\frac{1}{3}}, 1\right) if\ \beta_i < \frac{2s_i-1}{2q_i} \\ \left(\left[\frac{1-\beta_i}{6C}\right]^{\frac{1}{3}}, 0\right) if\ \beta_i > \frac{2s_i-1}{2q_i} \end{cases}, \tag{7}$$

with $C \in \left[0, \frac{1}{6}\right]$*. For* $\beta_i = 0 \Rightarrow q_i^* = 1$*, for* $C > \frac{1}{6} \Rightarrow q_i^* = 1$*, and for* $q_i^* = 1 \Rightarrow \begin{cases} v_i^* = 1\ if\ \beta_i < \frac{1}{2} \\ v_i^* = 0\ if\ \beta_i > \frac{1}{2} \end{cases}.$

The full mathematical analysis can be found in the Appendix. The agent's expected utility based on the amount of information acquisition is given by

$$E[U_i(q_i)] = \frac{1}{q_i}\sum_{s_i=1}^{q_i}\left[(1-\beta_i)\left(\frac{2s_i-1}{2q_i} - \beta_i\right)\left(\frac{2s_i-1}{2q_i} + \beta_i\right)\right] - C(q_i - 1). \tag{8}$$

By maximising Equation (8) with respect to parameter q_i, the optimal level of information acquisition q_i^* in the benchmark case is given by

$$q_i^* = \left[\frac{1-\beta_i}{6C}\right]^{1/3}. \tag{9}$$

Since the $q_i \in \mathbb{N}$, the optimal level of information acquisition indicated by the first-order condition might not be obtainable for the agent, as the optimal value could be real number that is not an integer. Another necessary condition of this model is that the amount of information acquisition is at least one, $q_i \geq 1$. To satisfy this boundary condition, the upper value of the agent's type β_i in order to acquire at least one information, is given by

$$\beta_i \leq 1 - 6C, \quad \text{with } C \in \left[0, \tfrac{1}{6}\right].^{6} \tag{10}$$

Besides a lower boundary, there is an upper boundary for the maximum amount of information acquisition q_i^*. When the agent's type β_i equals zero, the agent can deviate from the optimal amount of information acquisition q_i^*. For $\beta_i = 0$, the agent will deviate to no information acquisition $q_i^* = 1$ as this will result in a strictly higher utility. Using Equation (4) we find

$$U_i(q_i^*) < U_i(1),\ for\ \beta_i = 0, \tag{11}$$

because

$$(\alpha - 0)(\alpha + 0) - C(q_i^* - 1) < (\alpha - 0)(\alpha + 0),\ for\ \alpha > 0,\ q_i^* > 1. \tag{12}$$

Furthermore, the optimal value of the information collection parameter depends on both the agents type β_i and the costs of acquiring information C. Both relationships with q_i are negative, as expected:

$$\frac{\partial q_i}{\partial \beta_i} = \frac{1}{3(\beta_i - 1)}\left[\frac{1-\beta_i}{6C}\right]^{\frac{1}{3}} \leq 0, \qquad \text{with } \beta_i \in [0,1],\ C \in \left[0, \tfrac{1}{6}\right], \tag{13}$$

$$\frac{\partial q_i}{\partial C} = -\frac{1}{3C}\left[\frac{1-\beta_i}{6C}\right]^{\frac{1}{3}} \leq 0, \qquad \text{with } \beta_i \in [0,1],\ C \in \left[0, \tfrac{1}{6}\right]. \tag{14}$$

The equilibrium is characterised by both a negative relationship with the agent's personal investment β_i as well as the costs of acquiring information C. Figure 1 shows the optimal level of information acquisition q_i^* for different levels of personal investment β_i using the expected utility function as depicted by Equation (8). Lower costs of acquiring information C, as well as a lower personal investment β_i cause more information acquisition in equilibrium.

The optimal amount of information acquisition converges towards $q_i^* = 1$ as the expected reward in terms of utility of acquiring information is lower for higher levers of personal investment β_i. The probability that the agent votes $v_i = 1$ and obtains a utility higher than zero when personal investment β_i is high is very small, therefore acquiring costly information is more likely to only lead to higher costs without benefits. When the value of personal investment β_i becomes lower, there are larger benefits for acquiring information and decide on the implementation of the project based on information rather than to stay uninformed. Furthermore, when the personal investment β_i is equal to zero, there is no information acquisition as it leads to a strictly higher utility to deviate to acquire no information $q_i^* = 1$ and always vote in favour of implementation $v_i^* = 1$.

[6] Rewriting Equation (9) leads to $C \geq \frac{1-\beta_i}{6}$. As the agent's type follows a uniform distribution between zero and one, $\beta_i \sim U(0,1)$, the maximum value for the costs of information acquisition is found by approaching the limit of β_i. At the minimum value of β_i, the cost of information acquisition cannot exceed $\lim_{\beta_i \to 0}\left(\frac{1-\beta_i}{6}\right) = \frac{1}{6}$.

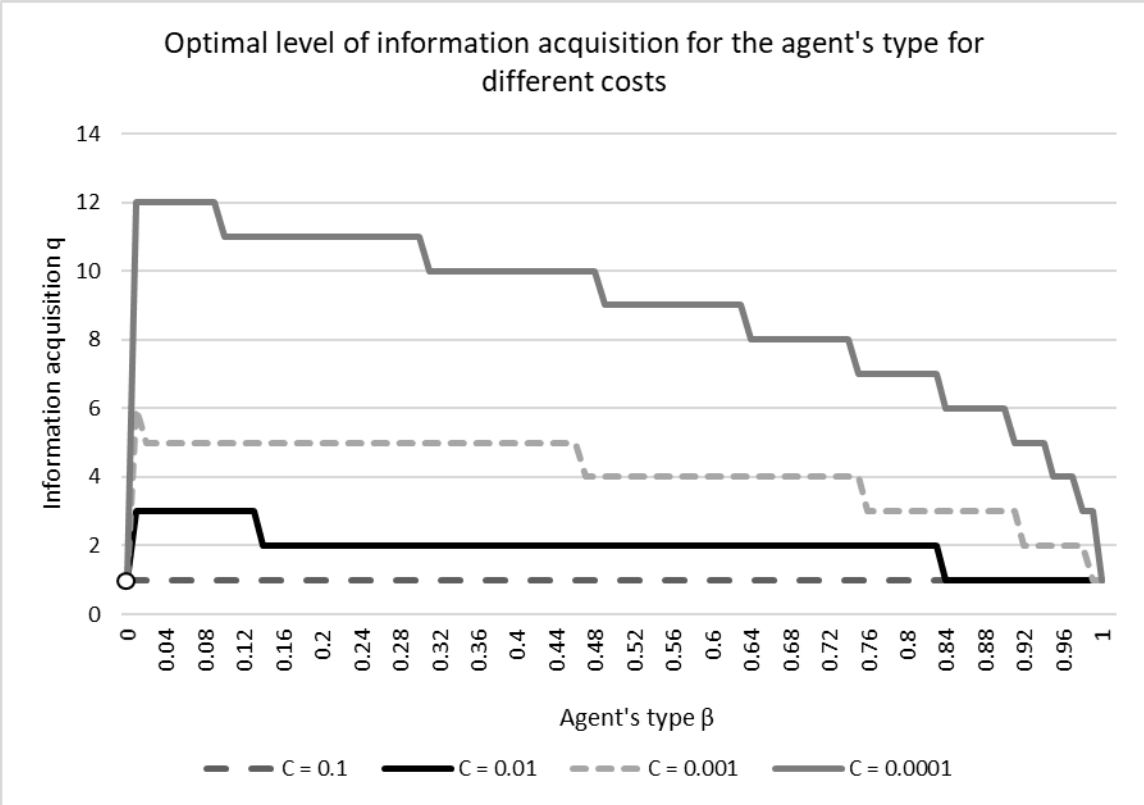

Figure 1: The optimal level of information acquisition q_i^* as given by Equation (9) for the agent's type β and different costs C under the pivotal vote assumption.

4.2 Homogeneous committee

Under the pivotal vote assumption an agent will acquire information vote following Proposition 2. In this section, I will analyse equilibrium solutions in the homogeneous committee with $n \in \mathbb{N}$ agents using the same steps as described in Section 4.1. In a committee with multiple agents the simple majority rule for the implementation of the project is employed which causes the decisions of the agents to become entangled. I will elaborate on the pivotal vote assumption and its implications on a pure strategy PBE as well as on a mixed strategy PBE. Also, both decision rules are discussed.

I will first elaborate on the fact that all agents in the homogeneous committee have the same type and therefore have the same β_i

$$\beta = \beta_1 = \cdots = \beta_i = \cdots = \beta_n, \tag{15}$$

which is public information; the agents know that the committee they are in is homogeneous. Since β is the same for all agents, $\Pr\left\{\beta < \frac{2s_i - 1}{2q_i}\right\}$ before receiving the signal s_i is also the equal for all agents. To find a pure strategy Perfect Bayesian Equilibrium, I consider two cases; (1) an equilibrium in which every agent collects information and (2) an equilibrium in which none of the agents collect information. Furthermore, I consider the possibility of a mixed strategy to be a PBE.

4.2.1 Pure strategy equilibrium

A similar personal investment β for all agents leads to the same utility maximising vote on the implementation of the project when all agents acquire information or when all agents do not acquire information. The agents will only vote $v_i = 1$ if they expect a positive payoff, which is when $\beta < \alpha$. The pure strategy equilibrium is the same for either voting rule, but it follows a different intuition. Proposition 3 describes this equilibrium. After describing this proposition, I will first analyse the pure strategy equilibrium under the simple majority voting rule followed by the equilibrium under the unanimity voting rule.

Proposition 3 *There exists a pure strategy Perfect Bayesian Equilibrium (q_i^*, v_i^*) that maximises the utility of agent i in a homogeneous committee where all agents vote uninformed according to Equation (6). The PBE is the same for both the simple majority and the unanimity voting rule. A pure strategy PBE is described by*

$$(q_i^*, v_i^*) = \begin{cases} (1,1), if\ \beta < 0.5 \\ (1,0), if\ \beta > 0.5 \end{cases}. \tag{16}$$

Employing a majority voting rule, the first consideration is whether there is a possibility that the agent has the pivotal vote. As all agents have a similar β, there is no possibility to alter the outcome of the vote. In both cases, when all agents acquire information and when all agents do not acquire information, they will all exert the same vote. This vote depends on the signal they would obtain if they would acquire information and depends on the agents' types β when they would vote uninformed. Consider an agent would deviate in the committee where all agents collect information. The agent would now choose to not acquire any information $q_i = 1$, and only votes according to his type β. In the smallest committee of $n = 3$, the agent will not have the pivotal vote as a differentiation of a single vote would lead to two votes versus one vote. For any larger committee, the impact of a single vote diminishes and therefore there is no possibility for an agent to alter the outcome of the vote. The same holds for a situation in which none of the agents acquires information and one agent decides to acquire information. Furthermore, deviating from no information collection $q_i = 1$ to information collection $q_i > 1$ incurs costs C per information collected for the agent, therefore his utility will be strictly lower than before he acquired information. This is described by

$$E[U_i(q_i > 1|v_i = 1)] < E[U_i(q_i = 1|v_i = 1)], \tag{17}$$

$$E[U_i(q_i > 1|v_i = 0)] < E[U_i(q_i = 1|v_i = 0)]. \tag{18}$$

Therefore, allowing only pure strategy equilibria, the agent will *never* have the pivotal vote in the homogeneous committee employing a majority voting rule.

Employing the unanimity voting rule results in the possibility of the agents to 'block' the project by voting against $v_i = 0$ and therefore there is a possibility that the agent is pivotal. However, the only possible scenario in which this strategy is pivotal is when all agents vote in favour $v_i = 1$. Consider an equilibrium where all the agents acquire information. A single agent could deviate from this strategy and vote always $v_i = 1$ without acquiring information because all agents have the same type and the project will be implemented only when its payoff is positive, $\beta < \alpha$. This results in

$$E[U_i(q_i = 1|v_i = 1)] > E[U_i(q_i > 1|v_i)]. \quad (19)$$

Applying this result to all agents would lead to an implementation of all projects without acquiring information. Implementing every project induces a lower utility than voting uninformed; when the agents are of type $\beta > 0.5$ they expect a negative payoff as given by Equation (5), the expected value of the project's profitability $E[\alpha] = 0.5$. Therefore, the agents will acquire no information $q_i = 1$ and vote based on their type β in a homogeneous committee employing a unanimity voting rule.

The result described in Proposition 3 holds for both voting rules. However, each voting rule follows a different intuition. Employing a simple majority voting rule induces the agents to vote uninformed because the agents' votes are never pivotal, while a unanimity voting rule induces the agents to vote uninformed because the agents will choose to deviate from acquiring information to a strategy in which they do not acquire information; the unanimity voting rule allows for free riding. The majority voting rule causes a single agent to have no impact on the outcome of the vote. The lack of information acquisition is in this case not because of free riding. However, the unanimity voting rule leads to no information acquisition because the agents are free riding; for types $\beta < 0.5$, the agents could alter the outcome of the vote made in equilibrium by acquiring information, but they will not acquire information because they will benefit by free riding.

4.2.2 Mixed strategy equilibrium

Playing a mixed strategy in a committee where every agent is the same type affects the probability of implementation. I assume that the agent has the pivotal vote, as an agent will only acquire information when his vote is pivotal. There exists a possibility that the agents' votes are pivotal when playing a mixed strategy as there could be enough agents that acquire information at the same time and vote accordingly. When there are enough agents that acquire information relative to those that will not acquire information following a mixed strategy, the assumption of the pivotal vote holds, and the voting rule does not matter.

I assume agents can only choose to mix the optimal amount of information collection as described by Equation (8), and no information collection, i.e. $q_i = \left[\frac{1-\beta_i}{6C}\right]^{1/3}$ and $q_i = 1$. Furthermore, I only consider mixed strategies where the agents play the same 'mix' of information collection; they all apply the same probability of acquiring the optimal amount of information as given by Equation (9).

The agent's collect the benchmark case optimal amount of information $q_i = \left[\frac{1-\beta_i}{6C}\right]^{1/3}$ with probability $\gamma \in [0,1]$ and they collect no information $q_i = 1$ with probability $(1-\gamma)$. Proposition 4 describes how there is a mixed strategy equilibrium for some combinations of the agent's type and the costs of acquiring information. When the agent's type is close to but below the cut-off value ($\beta = 0.5$) where agents change their vote in the pure strategy equilibrium, for some costs there is a mixed strategy equilibrium.

Proposition 4 *A mixed strategy Perfect Bayesian Equilibrium* (q_i^*, v_i^*) *maximises the utility of agent* i *for some combinations of the agent's type* β *and the cost of acquiring information* C*. A mixed strategy PBE only exists under the assumption that the agent's vote is pivotal and*

(i) *the agent's type* $\beta < 0.5$*,*

(ii) *the cost of acquiring information* C *is sufficiently small, satisfying the condition*

$$1 - 6\beta^2 > \left[\frac{6C}{1-\beta}\right] - \frac{3}{2}\left[\frac{6C}{1-\beta}\right]^{\frac{2}{3}}.$$

If these conditions are met, agent i *will mix with*

$$\gamma^* = \frac{(1-4\beta^2)}{\left[4\beta^3 - \frac{4}{3}\beta + \frac{1}{3} + 4C - \left((1-\beta)(6C)^2\right)^{\frac{1}{3}}\right]}, \tag{20}$$

where $\gamma^* \in [0,1]$ *denotes the probability with which the agent collects information according to the optimal amount of information acquisition* q_i^* *given by Equation (9) and* $(1-\gamma^*)$ *the probability with which the agent collects* $q_i^* = 1$*.*

For a mixed strategy to be a PBE, the expected utility of acquiring information and not acquiring information multiplied by their respective shares γ and $(1-\gamma)$ should be equal. Therefore, the following must hold

$$\gamma * E[U(q^*)] = (1-\gamma) * E[U_i(q_i = 1)].^{7} \tag{21}$$

When the agents that play the mixed strategy *do not* have a pivotal vote, the information acquired by the agents will only lead to higher costs, without increasing the payoff. As their vote is not pivotal, the initial outcome of the vote will not be changed by the collection of information, therefore, Equation (21) never holds.

[7] Note that q_i^* becomes q^* because $\beta_i = \beta$ in the homogeneous committee as shown by Equation (15).

When the agents that play the mixed strategy *do* have the pivotal vote, the possibility to mix and receive a higher utility depends on the agents' types β. When $\beta > 0.5$, the agents vote $v_i = 0$ if they decide not to acquire information and they will receive zero utility, as described by Proposition 3:

$$E[U_i(q_i = 1 | v_i = 0)] = 0. \quad (22)$$

For Equation (21) to hold when $\beta > 0.5$, either $\gamma = 0$ or $E[U(q^*)] = 0$. In both cases, there will not be a mixed strategy equilibrium as it is impossible to mix and receive a higher expected utility than the utility when the agents decide to play a pure strategy.

For $\beta < 0.5$, the agents vote $v_i = 1$ if they decide not to acquire information as explained at the end of Section 3. As the agents that play a mixed strategy are assumed to have the pivotal vote, Equation (21) is satisfied for values of γ as shown in Equation (20). Following this strategy, the agents expect to obtain a utility higher than playing a pure strategy of not acquiring information and voting $v_i = 1$. The values of β are all very close to $\beta = 0.5$, and the values for the costs are $C \in \left[0, \frac{1-\beta}{6}\right]$. The exact combinations are shown in Figure 2.

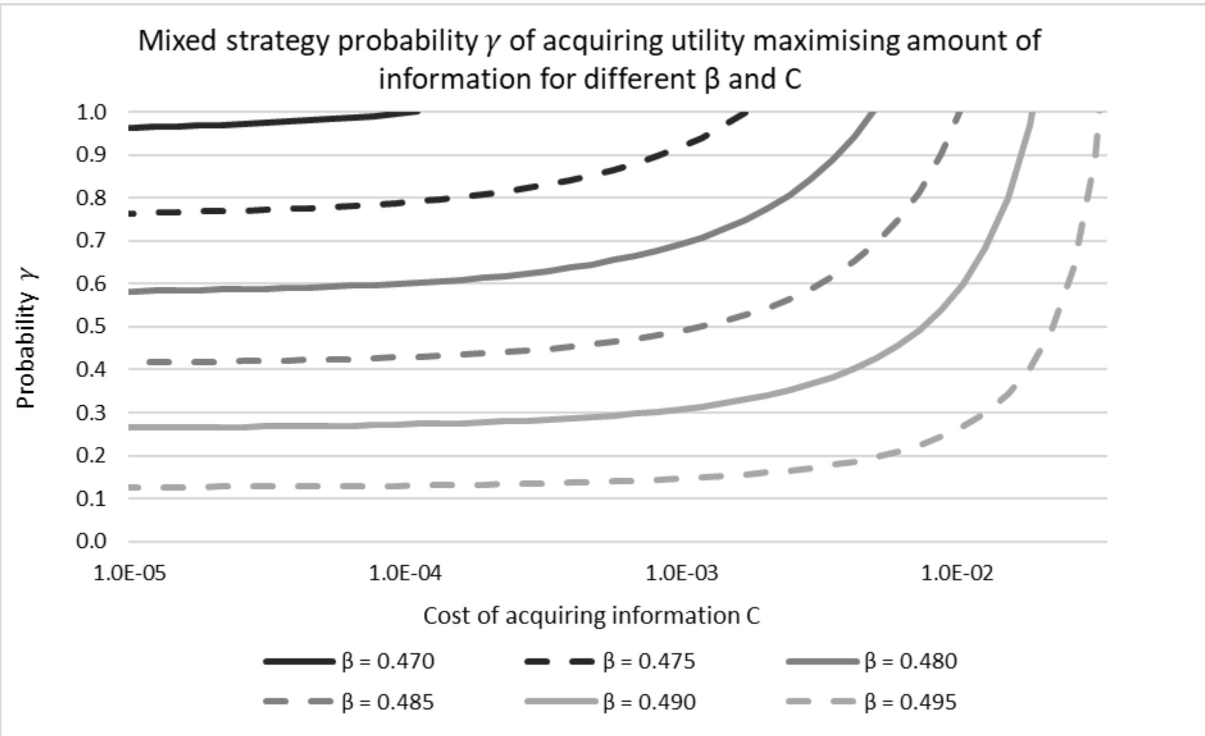

Figure 2: The probability γ of acquiring the utility maximising amount of information q_i^* as given by Equation (9) in a mixed strategy equilibrium. This figure shows the probability γ for a combination of (sufficiently low) costs of acquiring information C an several values of $\beta \in [0.47, 0.50]$. Note that (1) the range of combinations of β and C is continuous as $\beta \sim U[0,1]$, the depicted lines are indicators of the probability γ, and (2) the horizontal axis is logarithmic.

4.3 Heterogeneous committee

In the heterogeneous committee each agent has a different level of personal investment which is distributed uniformly between zero and one $\beta_i \sim U(0,1)$. Each agent knows his own β_i, and they know they are in a heterogeneous committee. In comparison with the homogeneous committee, each agent differs in his preference for the implementation of the project which leads to a differentiation between the agents' utility maximising vote. Furthermore, in a heterogeneous committee there exists a possibility that the agent has the pivotal vote. I will not discuss any mixed strategy equilibria in a heterogeneous committee as the assumption of pivotal votes can hold in this committee, which did not hold in the homogeneous committee. Consequently, the agents maximise their utility when they have the pivotal vote and acquire information accordingly. I will first describe a pure strategy Perfect Bayesian Equilibrium employing a majority voting rule. After that, I will describe this equilibrium using a unanimity voting rule. The difference between both equilibria is which agent is pivotal.

4.3.1 Majority voting rule

In this section I will employ a majority voting rule to analyse a pure strategy Perfect Bayesian Equilibrium in a heterogeneous committee. Consider an equilibrium in which all agents acquire information. The agents know in period one that the expected profitability of the project is equal to $E(\alpha) = 0.5$. An agent in period one forms expectations about the outcome of the vote when all agents acquire information and vote according to their signal and their type β_i. The vote of Agent 1 is pivotal if his vote determines the majority of the votes in favour of $v_i = 1$ or against $v_i = 0$ the project's implementation. This is the case when the sum of all other votes $\sum_i v_{i,i\neq 1}$ accounts for less than half of all the agents $\frac{1}{2}n$, but is higher than half the agents minus one vote, $\frac{1}{2}n - 1$. This is shown by

$$\frac{1}{2}n - 1 < \sum_i v_{i,i\neq 1} \leq \frac{1}{2}n. \quad (23)$$

When the votes are not divided equally, that is, when there is a large share vote $v_i = 1$ or $v_i = 0$ based on their type, none of the agents is pivotal and they can deviate from this strategy to a strategy where they do not acquire information. In this strategy, they vote uninformed according to Equation (6). This is the case when

$$\sum_i v_{i,i\neq 1} > \frac{1}{2}n, \quad (24)$$

$$\sum_i v_{i,i\neq 1} < \frac{1}{2}n - 1. \quad (25)$$

Knowing the agents vote uninformed, the agent with the median type *can* be pivotal and deviate from the strategy of voting uninformed to a strategy where he acquires the optimal amount of information as described by Equation (9) and vote according to the signal he receives. Note that the agent with the median *type* does not necessarily have the median *vote*, as the uninformed vote of the other agents in combination with the uniform distribution of types could lead to a clustering of agent types at either end of the distribution. This would mean the average agent type is biased towards the high or the low type β_i. In this situation, none of the agents is pivotal. The equilibrium strategy is described by Proposition 5.

Proposition 5 *In a heterogeneous committee employing a simple majority voting rule, only the agent that has the median type* β_i *can have the pivotal vote. This agent will acquire information, vote, and implement the project following the pure strategy described by Proposition 2.*

It is optimal for the agent with the pivotal vote to acquire information when the costs of information acquisition C are sufficiently low due to the risk aversity of the agents. Acquiring information allows the agent to only implement the project if he knows the project has a positive payoff. The optimal amount of information acquisition q_i^* for the agent's type β_i and the costs of information acquisition C can be found in Figure 1. As the agent determines the outcome of the vote, the situation is similar to the information acquired when the agent would be the sole decision maker on the implementation of the project as the expected utility for the pivotal vote becomes

$$E[U_1(v_1 = 1|s_1, q_1)] = \left(\frac{2s_1-1}{2q_1} - \beta_1\right)\left(\frac{2s_1-1}{2q_1} + \beta_1\right) - C(q_1 - 1), \tag{26}$$

$$E[U_1(v_1 = 0|s_1, q_1)] = -C(q_1 - 1). \tag{27}$$

For elaboration on this result I refer to the analysis in Section 4.1 as well as the Appendix. In this strategy, the agent will acquire his optimal amount of information as shown in Equation (9).

4.3.2 Unanimity voting rule

Changing the voting rule, I will analyse the equilibrium strategies employing a unanimity voting rule to in a heterogeneous committee. In this setting, a vote can only be pivotal when the votes of all other agents are in favour of $v_i = 1$ the implementation of the project and the agent decides to vote against $v_i = 0$. This situation occurs when the sum of all votes other than the vote of Agent 1, $\sum_i v_{i,i\neq 1}$, equals the sum of all agents minus one vote, $n - 1$. This is shown by

$$\textstyle\sum_i v_{i,i\neq 1} = n - 1. \tag{28}$$

When the votes are distributed otherwise, the vote of Agent 1 is not pivotal as another vote $v_{i,i\neq 1} = 0$ already stopped the projects implementation. Proposition 6 describes when the agents are pivotal and a pure strategy equilibrium of the information acquisition and voting behaviour of the pivotal agent.

Proposition 6 *In a heterogeneous committee employing a unanimity voting rule, only the agent that has the highest type β_i has the pivotal vote. This agent will acquire information, vote, and implement the project following the pure strategy described by Proposition 2.*

Consider an equilibrium in which all agents acquire information. An agent with a low personal investment $\beta_i < 0.5$ can deviate from the strategy in which he acquires information to a strategy where he does not acquire information because the expected payoff $E(\alpha) = 0.5$ is higher than his personal investment and therefore, the agent expects to vote $v_i = 1$ in Period 1. A vote in favour of the implementation of the project is not pivotal, and therefore the agent's utility is strictly higher when he does not acquire information. An informed agent with a high personal investment $\beta_i > 0.5$ could choose to vote $v_i = 1$ when the signal is higher than the agents type $\frac{2s_i-1}{2q_i} > \beta_i$, as described by Proposition 2. The agent's vote $v_i = 1$ is only pivotal if there is no other informed agent that has a higher personal investment β_i that votes $v_i = 0$. Therefore, only the agent with the highest personal investment β_i has the pivotal vote. This results in all agent that are not of the highest type β_i to deviate to a strategy in which they do not acquire information and always vote in favour: the agent with the higher β_i will block the implementation of the project when the project's payoff is too low, that is, when the signal is lower than the personal investment of the highest type agent $\frac{2s_i-1}{2q_i} < \beta_i$.

4.4 Committee size

Information acquisition depends on the pivotal vote notion. The agents could only know whether their vote was pivotal on the implementation of the project after they acquired information and exerted their vote. Therefore, the motivation to acquire information is determined by the agent's expectation of the influence of his vote; when the agent thinks he will have the pivotal vote, he will acquire information. In a homogeneous committee, the agents never acquire information because they either know they never have the pivotal vote or there is a possibility to free ride, dependent on the voting rule as described by Proposition 3. This pure strategy PBE holds for a both small and large committee size n, given the committee consists of an uneven number of agents. For a pure strategy PBE in a heterogeneous committee this is different; larger committees reduce the probability that an agent is pivotal. The negative relationship between committee size and information acquisition is described in Proposition 7.

Proposition 7 *Committee size has a negative effect on the probability that an agent is pivotal under both a majority and unanimity voting rule in a heterogeneous committee. This indicates a negative relationship between committee size and information acquisition in equilibrium.*

I will first describe the effect of committee size on the pivotal vote in a committee employing a majority voting rule and then the effect in a committee employing a unanimity voting rule. The majority voting rule allows the median type to have the pivotal vote. Starting in a large committee, the probability that the agent has the median vote is small. In a committee of size $n \to \infty$ the agent expects to have the pivotal vote when his type is equal to the expected value of the project's payoff. This holds for

$$\beta_i = E(\alpha) = 0.5. \tag{29}$$

In that case, the share of agents with a higher and lower type β_i is equal because the types are uniformly distributed $\beta_i \sim U[0,1]$. All the other agents know they are not pivotal and vote uninformed following Equation (6) and therefore the agent of the median type has the median vote. However, in a committee of size $n \to \infty$, the probability that there is an agent with exactly $\beta_i = 0.5$ is given by

$$\Pr[\beta_i = 0.5] = 0. \tag{30}$$

This indicates that the agent never has the pivotal vote in a committee with an infinite number of agents.

In a smaller committee there exists a range of agent types β_i for which the agent could expect his vote to be pivotal. Consider a committee of $n = 3$. Only when $\sum_i v_{i,i\neq 1} = 1$, the vote of Agent 1 is pivotal; by adding his vote to the sum either a majority is reached and the vote will pass or there are too little votes in favour and the vote will be rejected. This can be generalised to a committee of size $n \in \mathbb{N}$ as the vote is only pivotal when the sum of all votes is given by $\sum_i v_{i,i\neq 1} = \frac{1}{2}(n-1)$. Described by Proposition 5, only the median type can have this pivotal vote. When Agent 1 is pivotal, it is given that there are exactly as many agents of a higher type $\beta_{i,i\neq 1} > \beta_1$ as there are of a lower type $\beta_{i,i\neq 1} < \beta_1$ than that of Agent 1. The probability that Agent 1 has a higher type $\beta_{i,i\neq 1} < \beta_1$ than exactly $\frac{1}{2}(n-1)$ agents is given by

$$Pr\left[\beta_{i,i\neq 1} < \beta_1 \middle| \beta_1\right]^{\frac{n-1}{2}} = \beta_1^{\frac{n-1}{2}}. \tag{31}$$

Furthermore, the probability that Agent 1 has the lower type $\beta_{i,i\neq 1} > \beta_1$ than that same number of agents $\frac{1}{2}(n-1)$ is given by

$$Pr\left[\beta_{i,i\neq 1} > \beta_1 \middle| \beta_1\right]^{\frac{n-1}{2}} = (1-\beta_1)^{\frac{n-1}{2}}. \tag{32}$$

Multiply Equation (31) with Equation (32) to obtain the probability of one possible setting in which the type of Agent 1 is the median type and has the pivotal vote. To account for multiple orders in which this setting can occur, multiply this probability by the amount of possibilities in which this setting can occur; the number of permutations $\binom{n-1}{\frac{1}{2}(n-1)}$. This leads to Conjecture 1.

Conjecture 1 *The probability that an agent is pivotal using a majority voting rule in a heterogeneous committee is given by*

$$Pr[Pivotal|\beta_i] = \beta_i^{\frac{n-1}{2}} * (1-\beta_i)^{\frac{n-1}{2}} * \binom{n-1}{\frac{1}{2}(n-1)}. \tag{33}$$

The probability that the agent is pivotal decreases as the agent's type β_i is further away from the average type given the uniform distribution, $\beta_i = 0.5$. Equation (33) indicates that an increase in the committee size has a negative relationship with the agent's probability to have the pivotal vote. This is described by

$$\frac{\partial}{\partial n} Pr[Pivotal|\beta_i] < 0. \tag{34}$$

When the agent has a low probability to have the pivotal vote, he will acquire little to no information. This negative relationship is described in Proposition 7.

The analysis of the effect of committee size on information acquisition is completed by analysing the probability of being pivotal under a unanimity voting rule. Where the majority voting rule allows the median type to have the pivotal vote, the unanimity voting rule allows the highest type to have the pivotal vote as described by Proposition 6. Following the same intuition as used to form Conjecture 1, under a unanimity voting rule, Agent 1 is pivotal when the sum of all votes is given by $\sum_i v_{i,i\neq 1} = n-1$. The highest type holds the pivotal vote; therefore, all other agents need to have a lower type than the type of Agent 1, $\beta_{i,i\neq 1} < \beta_1$. Following the same steps as for Conjecture 1, this leads to Conjecture 2.

Conjecture 2 *The probability that an agent is pivotal using a unanimity voting rule in a heterogeneous committee is given by*

$$Pr[Pivotal|\beta_i] = \beta_i^{\,n-1}. \tag{35}$$

The probability that the agent is pivotal increases as the agent's type β_i approaches one. Similar to the majority voting rule, Equation (35) indicates that an increase in the committee size has a negative relationship with the agent's probability to have the pivotal vote as Equation (32) also applies to Conjecture 2. Under a unanimity voting rule, committee size has a negative effect on the information acquisition in equilibrium, as described by Proposition 7.

4.5 Effect of committee type and voting rule

In this section I will compare the findings to determine the differences between a homogeneous and a heterogeneous committee. The type of the committee influences the information acquisition in the committee and consequently whether the decision is informed or uninformed. Furthermore, the voting rule in combination with the committee type affects the profitability of the projects that are implemented as well as the agent's ability to free ride in the decision-making process.

The difference of the decision-making process between a homogeneous and a heterogeneous committee lies predominantly in the opportunity for the agents to implement a project based on information. Allowing only pure strategy equilibria, agents in a homogenous committee do not make decisions based on acquired information while under certain circumstances agents in a heterogeneous decide based on information. The possibility for mixed strategy equilibria causes agents to acquire information in a homogeneous committee, but compared to a heterogeneous committee, information acquisition only occurs with a very low probability. Corollary 1 describes this insight.

Corollary 1 *The type of the committee determines whether the decision is made informed or uninformed. A heterogeneous committee allows for informed decision-making in equilibrium as described by Proposition 5 and 6. Contrary, a homogeneous committee does not allow for informed decision-making in a pure strategy equilibrium as described by Proposition 3, and only very limited information acquisition in a mixed strategy equilibrium as described by Proposition 4.*

In a homogeneous committee, the type of voting rule does not change the equilibrium outcome, but it influences the path towards this equilibrium. As described in Section 4.2.1, a majority voting rule simply disables the agents to have any impact on the outcome of the vote which leads to no information acquisition in equilibrium. A unanimity voting rule allows the agents to be pivotal, but the fact that the agents are homogeneous induces free riding. Only when the committee is homogeneous, and the vote needs to be unanimous, free riding occurs.

Corollary 2 *Only in a homogeneous committee employing a unanimity voting rule there is a possibility for free riding. Proposition 3 describes the pure strategy equilibrium outcome in the homogeneous committee.*

The voting rule does not change the type of projects that are implemented in a homogeneous committee. The equilibrium outcome in both pure and mixed strategy equilibria is the same for each voting rule, although a unanimity voting rule in a mixed strategy equilibrium leads to a slight bias towards not implementing the project as the assumption of pivotal votes under a unanimity voting rule can only hold for votes against the implementation of the project. However, the mixed equilibrium strategy under the assumption of pivotal votes is the same for both voting rules.

Corollary 3 *In a homogeneous committee the voting rule does not influence the type of projects that are implemented. Proposition 3 and 4 describe the equilibrium outcomes in both pure and mixed strategies in the homogeneous committee.*

Unlike the outcome of the impact of the voting rule on the type of implemented projects in the homogeneous committee, the voting rule has an impact on the type of implemented projects in the heterogeneous committee. Employing a majority voting rule results in projects that have a payoff that is larger than the median type to be implemented. Employing a unanimity voting rule results in projects that have a payoff that is larger than the highest type to be implemented. Due to the quadratic property of the utility function, there is still a large gain for high type agents when they implement a project with an even higher profitability α under both voting rules. The quadratic increase in the project's profitability α causes the potential benefit from acquiring information to outweighs its costs, dependent on the agent's type β_i.

Corollary 4 *In a heterogeneous committee, employing a majority voting rule allows for a wider range of projects to be implemented compared to a setting in which a unanimity voting rule is employed. Under a unanimity voting rule, only projects with a high profitability will be implemented. Proposition 5 and 6 describe the equilibrium outcomes in the heterogeneous committee under a majority and unanimity voting rules respectively.*

There is no free riding in the heterogeneous committee as the agents are incentivised to acquire information if they have a chance to have the pivotal vote. Since each agent has a different level of personal investment, the utility maximising strategy is to acquire information according to Proposition 2 when this agent has the pivotal vote. Only for $\beta_i = 0$, an agent can deviate and always vote in favour without acquiring information.

5 Discussion

This paper analysed the information acquisition process in a committee decision model with endogenous information. By employing a sequential model in which the agents first decide to acquire costly information and vote accordingly, I show the difference in the amount of information acquired between a committee with homogeneous agents and a committee with heterogeneous agents. Also, I describe the influence of the employed voting rule on both the information acquisition in equilibrium as well as on the type of projects that are implemented. Furthermore, I show that committee size is important to incentivise agents to acquire information, but only in a heterogeneous committee.

I use a Perfect Bayesian Equilibrium concept to analyse the agents' strategies and show that in equilibrium, heterogeneous committees are more likely to make an informed decision while homogeneous committees abstain from acquiring information, except for the rare possibility to play a mixed strategy in equilibrium. I prove that only agents with a pivotal vote possibly acquire information. When an agent has the pivotal vote, it is optimal for an agent to acquire information to increase his expected utility. In a homogeneous committee the agents never acquire information because they are either never pivotal or they are better off free riding and vote uninformed, dependent on the voting rule. In a heterogeneous committee, the free rider problem is resolved and there is a possibility for the agents to have the pivotal vote and acquire information.

I find that there is no setting with more than one agent in which all the agents acquire the optimal amount of information. Agents in a homogeneous committee do not acquire information in pure strategy equilibria and in a heterogeneous committee the agents determine their information acquisition based on the probability that they are pivotal. The probability that the agent has the pivotal vote under a majority voting rule decreases as the agent's type moves away from the 'average' type. As there is still a probability for all agents to have the pivotal vote, there can be multiple agents that acquire a share of the optimal amount of information acquisition. This indicates that in a heterogeneous committee all the agents vote informed to some extent, dependent on committee size.

Employing a heterogeneous committee leads to more efficient decision-making compared to a homogeneous committee because there are more agents that acquire information. Also, only the agents that expect to be pivotal acquire information, which indicates that the agents in the committee do not incur costs of acquiring information without a return. Besides, the heterogeneous committee allows for higher quality decision-making as information acquisition leads to an informed vote. In the homogeneous committee, there is no information acquisition, and the agents vote uninformed. This committee will implement projects with a negative utility for all the agents, while the heterogeneous committee implements projects that results in a positive utility for at least half the agents.

This is similar for a unanimity voting rule, where the agent with the highest type has the highest probability of having the pivotal vote. The agent with the highest type will acquire his optimal amount of information with the largest probability, as he is pivotal. However, employing a unanimity voting rule will reduce the amount of information acquisition drastically as an agent with a high type, maximising his utility, only acquires a limited amount of information in equilibrium. The reason is for this is that there is a very low probability for the agent with the highest type to implement the project based on the information because the project is most likely to have a lower profitability than the agent's personal investment. This results in the implementation of only highly profitable projects, based on a limited amount of information. When a committee is designed, it is important to employ the right voting rule as it influences information acquisition in equilibrium as well as the type of projects that are implemented.

The insights of the analysis of the model describe how expertise in committees influences decision-making. Committees with experts on different areas, or with employees with different functions have a higher incentive to acquire information before voting on a project. This is beneficial for both the agents, as they can obtain a higher utility, and anyone who has an interest in the project because compared to a committee with homogeneous agents, there is more information acquisition. As the agents vote based on acquired information and their expert preference, implemented projects are a product of rational decisions.

In this paper I assume that the agents know in what type of committee they reside, but do not know the types of the other agents. When agents can observe the other agents type it would alter the equilibrium outcomes in the heterogeneous committee. The information acquisition and voting stage would be more strategic; the agents will acquire information and vote strategically based on the types of the other agents. This would increase free riding; when agents can observe each other's types, it enables the agents to form expectations on the project preferences of others. The different expertise of each agent is likely to be known within the committee, therefore this could be interesting for further research.

The model I discuss could be extended by adding communication. Allowing for communication after acquiring information would influence the agents' incentive to acquire information, as the agents are able to extract information from others. within committees, before voting, is an extension that is discussed in the literature. Furthermore, different types of utility functions could be used to analyse the information acquisition in this model. I used a quadratic utility function for the utility of the agents to be concave in the benefits of acquiring information. Also, voting rules that are different than the two widely used voting rules that I discussed can be implemented to analyse their implications on the information acquisition in both types of committees.

6 References

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7 Appendix

7.1 Proof of Proposition 2

The agent is in period two. The expected project payoff $(\alpha - \beta_i)$ for agent i given the signal s_i and the information collection parameter q_i is given by Equation (1). The agent has an expectation on the project's profitability $\alpha \in \left[\frac{s_i-1}{q_i}, \frac{s_i}{q_i}\right]$. The agent will only vote $v_i = 1$ if he expects the project yields a positive payoff, which is when $\beta_i < \alpha$. The expected value for α is given by the combination of the signal s_i and the information collection parameter q_i, which results in

$$\beta_i < \frac{2s_i-1}{2q_i}. \tag{A1}$$

Furthermore, when the agent votes $v_i = 1$, the probability of implementation $p = 1$ since there is only one agent. From Equation (4) follows

$$E[U_i(v_i = 1|s_i, q_i)] = \left(\frac{2s_i-1}{2q_i} - \beta_i\right)\left(\frac{2s_i-1}{2q_i} + \beta_i\right) - C(q_i - 1) \tag{A2}$$

$$E[U_i(v_i = 0|s_i, q_i)] = -C(q_i - 1). \tag{A3}$$

The probability of voting $v_i = 1$ before obtaining signal s_i is equal to the expected project payoff given by Equation (1). Since $\beta_i \sim U(0,1)$, the probability that any value between zero and one occurs is the same. For any value between zero and one, the probability that β_i is smaller than that value is equal to that value. Therefore, the probability of voting $v_i = 1$ is given by

$$\Pr\{v_i = 1\} = \Pr\{\beta_i < \alpha\} = 1 - \beta_i. \tag{A4}$$

And the probability of voting $v_i = 0$ is given by

$$\Pr\{v_i = 0\} = \Pr\{\beta_i \geq \alpha\} = \beta_i. \tag{A5}$$

To find the expected utility *before* voting v_i, but *after* obtaining the signal s_i, multiply the expected utilities from voting, Equation (A2) and Equation (A3,) with their respective probabilities, Equation (A4) and Equation (A5):

$$E[U_i(s_i, q_i)] = \Pr\{v_i = 1\}\left[\left(\frac{2s_i-1}{2q_i} - \beta_i\right)\left(\frac{2s_i-1}{2q_i} + \beta_i\right) - C(q_i - 1)\right]$$

$$+ \Pr\{v_i = 0\}\,[-C(q_i - 1)].$$

Substitute and rewrite using Equation (A4) and (A5)

$$E[U_i(s_i, q_i)] = (1 - \beta_i)\left[\left(\frac{2s_i-1}{2q_i} - \beta_i\right)\left(\frac{2s_i-1}{2q_i} + \beta_i\right)\right] - C(q_i - 1). \tag{A6}$$

The agent is in period one. The expected utility before learning the signal s_i (Equation (5)) can be obtained by taking the sum of the expected utility for all possible signals given the level of information acquisition, $s_i \in \{1,2,\ldots,q_i\}$, and divide this by q_i so that

$$E[U_i(q_i)] = \frac{1}{q_i}\sum_{s_i=1}^{q_i}\left[(1-\beta_i)\left[\left(\frac{2s_i-1}{2q_i}-\beta_i\right)\left(\frac{2s_i-1}{2q_i}+\beta_i\right)\right]-C(q_i-1)\right].$$

Use

$$\frac{1}{q_i}\sum_{s_i=1}^{q_i}\left[\left(\frac{2s_i-1}{2q_i}-\beta_i\right)\left(\frac{2s_i-1}{2q_i}+\beta_i\right)\right] = \frac{1}{3}-{\beta_1}^2-\frac{1}{12{q_1}^2}, \tag{A7}$$

and rewrite

$$E[U_i(q_i)] = (1-\beta_i)\left(\frac{1}{3}-{\beta_1}^2-\frac{1}{12{q_1}^2}\right)-C(q_i-1). \tag{A8}$$

To find the optimal value of the information collection parameter q_i, maximise the expected utility, Equation (A8), with respect to q_i. The first-order condition is given by

$$\frac{\partial E[U_i(q_i)]}{\partial q_i} = 0. \tag{A9}$$

This implies

$$\frac{\partial E[U_i(q_i)]}{\partial q_i} = \frac{1-\beta_i}{6{q_i}^3}-C = 0.$$

Rewrite to find the optimal amount of information collection as shown in Equation (7).

7.2 Proof of Proposition 4

The agents are in period two. Consider the case in which the agents have the pivotal vote. In a pure strategy equilibrium, none of the agents collect information and they vote based on their type β. This results in the separation in voting based on β as shown in Equation (15). First, I analyse a mixed strategy for the case in which $\beta > 0.5$. The agents vote $v_i = 0$ if they decide not to acquire information, as described by Proposition 3. The expected utility of not collecting any information $q_i = 1$ is given by (Equation (23))

$$E[U_i(q_i = 1|v_i = 0)] = 0.$$

Furthermore, the expected utility of collecting the optimal amount of information as given by Equation (7) can be found by substituting q^* in Equation (A8). This gives

$$E[U(q^*)] = (1-\beta)\left(\frac{1}{3}-\beta^2-\frac{1}{12{q^*}^2}\right)-C(q^*-1). \tag{A10}$$

To find the probability γ for which a mixed strategy could be an equilibrium, the expected utility of acquiring the optimal amount of information (Equation (A28)) must equal the expected utility of acquiring no information (Equation (23)), multiplied by each respective probability γ and $(1-\gamma)$, such that

$$\gamma\left[(1-\beta)\left(\frac{1}{3}-\beta^2-\frac{1}{12q^{*2}}\right)-C(q^*-1)\right]=(1-\gamma)*0. \tag{A11}$$

This holds for $\gamma=0$ and for

$$(1-\beta)\left(\frac{1}{3}-\beta^2-\frac{1}{12q^{*2}}\right)-C(q^*-1)=0. \tag{A12}$$

In both cases this would mean that there is no possibility to play a mixed strategy and obtain a higher utility.

Second, I analyse a mixed strategy for the case in which $\beta<0.5$. In this case, the agents vote $v_i=1$ if they decide not to acquire information, as described by Proposition 3. The expected utility of not collecting any information $q_i=1$ is given by

$$E[U_i(q_i=1|v_i=1)]=(0.5-\beta)(0.5+\beta). \tag{A13}$$

Also, the expected utility of collecting the optimal amount of information is the same as previously described in Equation (A10). Equating both expected utilities and multiplying them by their respective probability γ and $(1-\gamma)$ leads to

$$\gamma\left[(1-\beta)\left(\frac{1}{3}-\beta^2-\frac{1}{12q^{*2}}\right)-C(q^*-1)\right]=(1-\gamma)(0.5-\beta)(0.5+\beta). \tag{A14}$$

Rewrite

$$\left(\frac{1}{4}-\beta^2\right)=\gamma\left[\beta^3-\beta^2-\frac{1}{3}\beta+\frac{1}{3}-\frac{(1-\beta)}{12q^{*2}}-C(q^*-1)\right]-\gamma\left(\frac{1}{4}-\beta^2\right)$$

$$=\gamma\left[\beta^3-\frac{1}{3}\beta+\frac{1}{12}-\frac{(1-\beta)}{12q^{*2}}-C(q^*-1)\right]. \tag{A15}$$

Substitute Equation (6) in Equation (A15) to find

$$\left(\frac{1}{4}-\beta^2\right)=\gamma\left[\beta^3-\frac{1}{3}\beta+\frac{1}{12}-\frac{(1-\beta)}{12\left(\left[\frac{1-\beta}{6C}\right]^{\frac{1}{3}}\right)^2}-C\left(\left[\frac{1-\beta}{6C}\right]^{\frac{1}{3}}-1\right)\right]$$

$$=\gamma\left[\beta^3-\frac{1}{3}\beta+\frac{1}{12}-\frac{1}{4}(1-\beta)^{\frac{1}{3}}(6C)^{\frac{2}{3}}+C\right]. \tag{A16}$$

Rewrite to find the probability γ (Equation (21))

$$\gamma = \frac{(1-4\beta^2)}{\left[4\beta^3-\frac{4}{3}\beta+\frac{1}{3}+4C-\left((1-\beta)(6C)^2\right)^{\frac{1}{3}}\right]}.$$

The probability $\gamma \in [0,1]$ only falls between its upper and lower bound value for some specific combination of the agent's type β and the costs of information acquisition C. Figure 2 shows for which combinations this holds, and which share γ could comprise a mixed strategy. As $\gamma \in [0,1]$, there only exists a mixed strategy equilibrium if the numerator is smaller than the denominator. This results in a (necessary) condition for both the costs C and the agent's type β. The condition is denoted as follows

$$(1-4\beta^2) < 4\beta^3 - \frac{4}{3}\beta + \frac{1}{3} + 4C - \left((1-\beta)(6C)^2\right)^{\frac{1}{3}}. \quad \text{(A17)}$$

Rewrite to find

$$1 - 6\beta^2 > \left[\frac{6C}{1-\beta}\right]^{\frac{2}{3}}\left(\left[\frac{6C}{1-\beta}\right]^{\frac{1}{3}} - \frac{3}{2}\right). \quad \text{(A18)}$$

This leads to a mixed strategy Perfect Bayesian Equilibrium where agent i acquires the optimal amount of information according to Equation (7) with probability γ^* as denoted by Equation (21) and acquires no information with probability $(1-\gamma^*)$.