

Social Pressure, Transparency, and Voting in Committees*

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Abstract

We examine the consequences of vote transparency in committees whose members fear being blamed by partisan observers for casting an unfavorable vote. We show that such social pressure, like optimal taxation, can improve the collective decision by mitigating a voting externality. Hence, institutions may adopt public voting when the fear of blame is too little, and secret voting when the fear is too much. We also show that public voting is particularly desirable in committees with overly biased members or overly biased voting rules against the alternative.

Keywords: Committee, blame, transparency, social pressure

JEL Classification: D02, D71, D91

“Man is by nature a social animal.” – Aristotle, *Politics*

1 Introduction

Many economic and political issues are decided by committees. Notable examples include job promotions, new drug approvals, and legislative bills. Perhaps, the greatest advantage of a committee is to draw upon the diverse opinions of its members. Therefore, it seems only democratic that committee members convey their opinions freely without feeling pressured by interested observers such as job candidates, patient groups, and political party leaders. Indeed, there is substantial evidence that decision-makers care about social pressure and would

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take costly measures to avoid it.¹ In this paper, we argue that while it may be individually undesirable for committee members, social pressure, much like taxation, can lead to better collective decisions by correcting for a voting externality. As such, institutions may favor more transparency in voting to increase social pressure when it is too low, and less transparency when it is too high.

Our base model features a group of experts who vote whether or not to accept a complex, multi-dimensional “project” according to the unanimity rule. Given his specialty, each expert can evaluate the quality of only one dimension and is biased toward it. We depart from the extant literature (discussed below) by assuming that besides the decision on the project, each expert is concerned about being blamed by the partisan observer (e.g., the job candidate or patient group) for casting an unfavorable vote so far as his vote can be inferred.^{2,3} Hence, social pressure that experts may feel depends crucially on the transparency of the voting procedure, and we initially compare two such procedures: public vs. secret voting, whereby either the entire vote profile or only the committee’s decision is disclosed to the observer. We assume that the disclosure regime is chosen at an *ex ante* stage by an uninformed, utilitarian planner who maximizes the average quality of accepted projects, perhaps having the greater society in mind.

Our first observation is that in a blame-free environment, each biased expert would be too demanding on his dimension of the project by excessively voting down an otherwise high-quality project. Indeed, to correct for this negative “voting externality,” the planner would dictate each expert to lower his acceptance standard and do so more in a larger committee in which the externality is more pronounced. In practice though, the planner cannot dictate experts’ voting strategies due to their private knowledge on the issue, but she can influence them through social pressure. Our main finding is that if experts worry little about the blame, the planner *strictly* prefers public voting to amplify their worries (at the margin) whereas if their concern for blame is significant, the planner *strictly* prefers secret voting to diminish their

¹The evidence on social pressure covers a variety of settings: decision-making by committee (Gole and Quinn, 2016; Harmon et al. 2017); voter turnout (Gerber et al. 2008; DellaVigna et al., 2017), charitable giving (Dana et al. 2006; DellaVigna et al. 2012); referee favoritism in soccer (Garicano et al., 2005), and team work (Mas and Moretti, 2009), among others.

²Gurdal et al.(2013) define blame as “the channeling of negative feelings produced by an undesirable event toward someone associated with that event.” Our take on blame is consistent with this definition. It is also consistent with the definition of Celen et al.(2017) based on “what you [would] have done in your opponent’s situation” in that in our model, the partisan observer’s eagerness for the project’s acceptance is common knowledge.

³Blame may be borne by internal feelings or external sanctions, amplifying with the expert’s social ties and shared characteristics with the observers as well as their number.

concern. Hence, much like the optimal taxation for the provision of public goods, there is an optimal level of social pressure that the planner wants for committee members to mitigate the voting externality.⁴ By the same logic, we also find that the planner is more likely to choose public voting in a larger committee, evaluating, perhaps, a more complex project.

Note that when influencing the voting behavior, the planner targets each expert's "marginal" type, who is indifferent between Yes and No votes. In particular, by public voting, the planner aims to compound the marginal effect of blame; and to diffuse it, the marginal type of the expert would prefer secrecy.⁵ This incentive is, however, not uniform across the infra-marginal types. For instance, an expert who is strongly in favor of the project would opt for public voting to avoid any blame. Somewhat surprisingly, we find that despite increasing its marginal effect, public voting decreases the expected (or average) blame. Hence, from an *ex ante* perspective, we find little tension between the planner and committee members about increasing transparency.⁶

To isolate social pressure as the unique source of strategic voting, and easily compare the voting procedures, we have made three main assumptions in the base model: an all-or-nothing disclosure regime; extremely biased experts (with independent private values for the project); and the unanimity rule for consensus. We relax each assumption in Section 5 and show that our insights are robust, though new ones emerge. Specifically, we show that if available, a partially public voting procedure, whereby only the vote count is revealed to the outside observer, would be strictly optimal for a moderate level of blame, reinforcing our previous conclusion: the less concerned experts are about being blamed, the more transparent the voting procedure should be. We, then, extend our analysis to less biased experts who also weigh other dimensions of the project, creating an additional source of strategic voting (as in Moldovanu and Shi, 2013). In particular, we find that with such interdependent preferences, experts lower their acceptance standards, the less biased they are toward their expertise, diminishing the planner's need for social pressure to correct for the voting externality mentioned above. As such, all else equal, we predict more transparent voting in committees that

⁴This may rationalize why the president's "arm-twisting" of legislators is not considered undemocratic per se; see www.cnn.com/2017/03/21/politics/trump-health-care/index.html

⁵There is compelling experimental evidence that decision-makers often seek to diffuse blame; e.g., by delegation (Hamman et al. 2010; Bartling and Fischbacher, 2011), or by moral "wobble room" (Dana et al. 2007; Falk and Szech, 2013). In our model, secrecy of voting provides the necessary wobble room whose extent is determined in equilibrium.

⁶The tension over the level of transparency may, of course, be inevitable *ex post* once experts become privately informed of the project, in which case those who plan to vote No would want secrecy. But the issue of designing an institution appears more relevant from an *ex ante* perspective.

contain more partisan experts. Last, but not least, we consider general voting rules. By fully characterizing the optimal voting rule in a blame-free environment, we establish that coupled with this rule, which already eliminates the voting externality, the planner would favor secrecy. In practice though, the planner is unlikely to tailor the voting rule for each specific issue, e.g., each job promotion or each legislative bill, leaving room for social pressure and transparency to play a role.

Overall, our investigation reveals that transparent voting is likely to improve the committee's decision when: its members are little concerned about blame; they are overly biased toward own expertise, i.e., the committee is a "team of rivals"; or the consensus rule is sub-optimal for the issue at hand.

Related Literature. Aside from the empirical papers on social pressure and blame-sharing cited above, our paper is related to those on committee voting with "mixed motives": besides the decision, each member may care about, e.g., being on the winning side (Callander, 2008), expressing his ideology (Morgan and Vardy, 2012), or *ex post* decision errors (Midjord et al. 2017). The non-instrumental motive in these papers is, however, purely internal, so transparency is a nonissue. In this regard, our paper is closer to Gradwohl (2017), who adds a preference for privacy to a Condorcet Jury model, and like us, compares various disclosure regimes. Gradwohl finds that public voting is socially optimal because by rendering privacy irrelevant, it induces sincere voting, and that voter privacy may be best insured under partially public voting. Our model is different from his in at least two respects. First, voting is always strategic under blame avoidance, and depending on the level of blame, each disclosure regime can be socially optimal. Second, voting aggregates preferences – not information – in our model; as such, it is more in line with those of Levy (2007), Albrecht et al. (2010), and Moldovanu and Shi (2013). Levy considers the effect of transparency on collective decision-making with career concerns and finds general support for secret voting.⁷ Social pressure is different from career concerns because it is individually disliked by committee members, but much like taxation, it may be used by the planner to correct for a voting externality. Moreover, unlike career concerns, social pressure affects decision-makers whether or not the outcome is realized in the immediate future. Albrecht et al. and Moldovanu and Shi study a collective search problem with pure private (or more generally, interdependent) values for the project, which our static setup builds on.

⁷Other papers in this line of research include Ottaviani and Sørensen (2001), Swank and Viser (2007), Gersbach and Hahn (2011), Matozzi and Nakaguma (2016), and Fehrler and Hughes (Forthcoming).

By incorporating social pressure into committee decisions, our paper is also related to Gole and Quinn (2016), and Chemmanur and Fedaseyau (2017). Gole and Quinn explore a complementary setting to ours, in which committee members feel social pressure to agree with each other – not from a partisan, non-voting observer – and in turn, they may over weigh public information to coordinate their votes. Chemmanur and Fedaseyau study a board’s decision whether or not to fire the CEO, taking into account the possibility that each board member may face retaliation for dissent if the CEO is retained. Neither paper, however, considers transparency as an optimal institution.

Finally, our paper is related to the literature on vote buying. In particular, Dal Bo (2007) shows in a complete information setting that the committee can be captured at virtually no cost if the voting is public and the agreement requires less than unanimity. Name-Correa and Yildirim (2017) argue the benefits of the size and secrecy of committees in deterring capture. Unlike in this literature, social pressure cannot be fully controlled by the interested observer.⁸

The remainder of the paper is organized as follows. In the next section, we lay out the baseline model. In Section 3, we characterize equilibrium under both public and secret voting procedures, followed by a comparison of the two from a social perspective in Section 4. In Section 5, we extend the analysis to partially public voting, interdependent valuations, and general voting rules. Section 6 concludes. Proofs of all formal results are relegated to an appendix.

2 The model

A committee of $n > 1$ risk-neutral experts must decide whether or not to accept a complex, multi-dimensional “project” – e.g., a job promotion, a new drug approval, or a healthcare bill. Based on his specialization, expert i can assess the quality of only one dimension, which yields a private signal s_i independently drawn from a continuous distribution $F : [s_L, s_H] \rightarrow [0, 1]$, with a positive density f and normalized mean $E[s_i] = 0$, implying $s_L < 0 < s_H$. Expert i is assumed to be biased toward his specialization so that his valuation of the project is his signal: $v_i = s_i$. This assumption allows us to isolate the effect of social issues on voting behavior, but such pure private values for the project may also represent different constituencies or a division of labor in the committee, though our results readily extend to more general (interdependent) preferences, as we show in Section 5.2. Upon observing their private signals,

⁸For instance, even if a job candidate does not approach the committee, its members may still feel social pressure due to cultural ties and shared characteristics.

committee members simultaneously vote Yes/No, and the project is accepted if the vote is unanimously affirmative.⁹ A rejected project yields a normalized payoff of $v_i = 0$, so experts are *ex ante* unbiased about the project.

The main departure of our setup from the extant literature is that in addition to the decision on the project, each expert cares about being blamed by partisan observers – e.g., job candidates, patient groups, or the president – for casting a negative vote.¹⁰ In particular, each expert is assumed to receive a fixed disutility $b > 0$ to the extent that the outside observer learns or infers his vote to be No.¹¹ This will, however, depend on the disclosure regime (d) adopted by the organization, and we initially compare two such regimes: public vs. secret voting, whereby either every vote or only the committee’s decision is revealed to the outside observer. (A less extreme or “partial” disclosure regime is considered in Section 5.1)

Let $\sigma_i^d : s_i \rightarrow \{\text{Yes, No}\}$ denote expert i ’s equilibrium voting strategy under d , and $\sigma^d(\mathbf{s}) = (\sigma_1^d(s_1), \dots, \sigma_n^d(s_n))$ be the resulting vote profile. We assume that at an *ex ante* stage, an uninformed planner, representing the organization, chooses d that maximizes the average quality of accepted projects:

$$w = E \left[\frac{\sum_i s_i}{n} \mid \sigma^d(\mathbf{s}) \right]. \quad (1)$$

From (1), it is clear that the planner has a direct preference only for the project, but she will take social issues facing experts into account through their equilibrium strategies. It is also clear that besides maximizing the average quality, the planner can be considered as a utilitarian, aggregating the preferences of committee members for the project.

As is common in the literature, we solve for the symmetric Bayesian-Nash equilibrium of the voting game, which, given *ex ante* symmetric experts, appears reasonable. We begin our analysis by characterizing the optimal and equilibrium voting strategies and then examine the planner’s disclosure choice.

⁹For applications and the potential optimality of unanimity rule, see, e.g., Bond and Eraslan (2010), Alonso and Camara (2016), and Breitmoser and Valasek (2017). We consider general voting rules in Section 5.3.

¹⁰In theory, experts may also hope to receive credit for a positive vote. However, in an influential paper, Weaver (1986) argues, at least within politics, that “politicians are motivated primarily by the desire to avoid blame for unpopular actions rather than by seeking to claim credit for popular ones.”

¹¹As will be clear in the analysis, expert i ’s voting strategy is determined solely by the ratio $\frac{s_i}{b}$. Hence, we could alternatively assume a privately known disutility, b_i , and work with the random variable $\frac{s_i}{b_i}$. We opted for the current approach for exposition.

3 Analysis

Note that if experts did not worry about the blame, i.e., $b = 0$, then, given pure private values, each would follow a simple dominant strategy: accept the project if $s_i > 0$, and reject it otherwise. That is, each expert would demand a standard no less than the status quo for his dimension of the project. This strategy, however, is not optimal for the planner who values all dimensions. To see why, suppose that the planner could dictate the cutoff, x , for the votes such that expert i would approve the project whenever $s_i > x$. Then, with the unanimity rule and *iid* signals, the project would be approved with probability $[1 - F(x)]^n$, and in turn, the planner's expected welfare would be

$$\begin{aligned} w(x, n) &= [1 - F(x)]^n \left(\frac{nE[s|s > x]}{n} \right) \\ &= [1 - F(x)]^{n-1} \int_x^{s_H} s dF(s). \end{aligned}$$

where $E[s|s > x]$ is the mean signal conditional on a Yes vote. Letting $\phi = 1 - F(x)$ be the probability of a Yes vote, or equivalently, $x = F^{-1}(1 - \phi)$, the planner's optimal voting problem can be expressed more succinctly as:

$$\max_{\phi \in [0,1]} w(\phi, n) = \phi^{n-1} \int_{F^{-1}(1-\phi)}^{s_H} s dF(s). \quad (2)$$

Lemma 1 *There is a unique solution, $\phi^o(n)$, to (2), and $\phi^o(n) \in (1 - F(0), 1)$. Moreover, (a) $\phi^o(n)$ is strictly increasing in n ; (b) $\phi^o(n) \rightarrow 1$ and $(\phi^o(n))^n \rightarrow \frac{1}{e} \approx .37$ as $n \rightarrow \infty$.*

The uniqueness follows because $w(\phi, n)$ is single-peaked in ϕ , trading off the likelihood of a consensus and the signal value of a Yes vote. Lemma 1 says that the planner would optimally instruct each expert to relax his acceptance standard (below 0); see Figure 1. In doing so, the planner aims to correct for a negative "voting externality" in the committee in case one expert draws a small negative signal and blocks an overall high-quality project. Since this externality multiplies with the committee size, so does the the optimal probability of acceptance that corrects for it, approaching 1 in the limit, although the probability that the project is approved remains bounded away from 1 – about .37.

It is worth noting that the optimal voting strategy, $\phi^o(n)$, is independent of the disclosure regime, d , since by assumption, the planner is not directly concerned about the committee's exposure to social pressure. In practice, though, the planner cannot dictate experts' voting strategies due to their privately held signals. Moreover, in the presence of social pressure,

voting is likely to be strategic, and depend on whether it is public or secretive, which we turn to in the next two subsections.

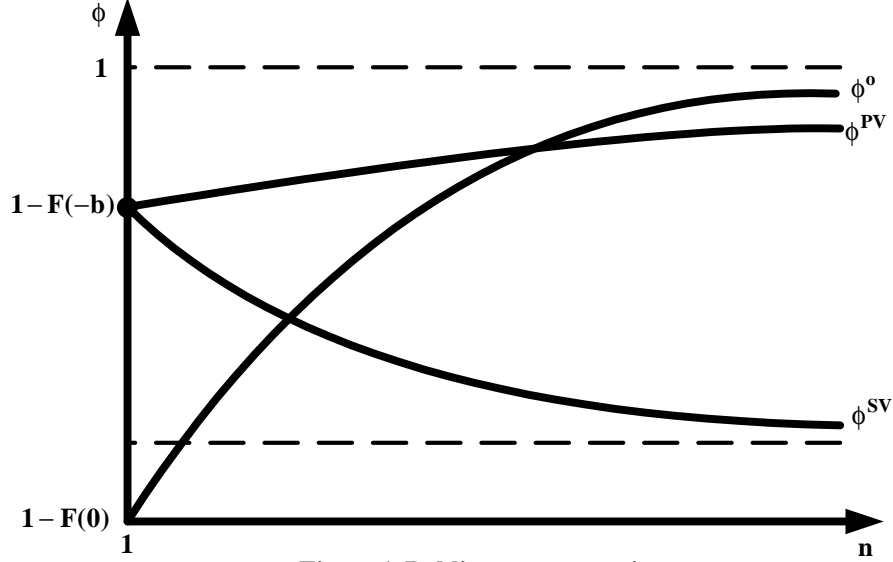


Figure 1. Public vs. secret voting

3.1 Public voting

Suppose that the planner commits to disclosing each vote. In a symmetric equilibrium, let ϕ be the probability that a given expert accepts the project. Then, expert i votes Yes if it is in his best interest conditional on being pivotal, namely, if:

$$\phi^{n-1}s_i > -b. \quad (3)$$

Being a pivotal voter, expert i trades off his expected payoff from voting Yes, thereby inducing the project's approval and avoiding blame, against his expected payoff from voting No, thereby inducing the project's disapproval and receiving the disutility b for his unfavorable vote. From (3), we, therefore, have in equilibrium:

$$\phi = 1 - F\left(-\frac{b}{\phi^{n-1}}\right), \quad (4)$$

where the term $\frac{b}{\phi^{n-1}}$, which clearly exceeds b , can be interpreted as the "effective blame" suffered by each expert at the margin.¹² Let $\phi^{PV}(n, b)$ be a solution to (4); see Figure 1.

¹²The idea of the effective blame is that it would induce the same voting strategy if the expert were alone.

Lemma 2 $\phi^{PV}(n, b)$ uniquely exists. Moreover, $\phi^{PV}(n, b)$ is increasing in b and n , with $\phi^{PV}(\cdot) \rightarrow 1$ and $(\phi^{PV}(\cdot))^n \rightarrow \min\{\frac{b}{|s_L|}, 1\}$ as $n \rightarrow \infty$.

The fact that an expert lowers his acceptance standard in response to greater social pressure, b , is intuitive, especially because votes are public. To understand why he also lowers it in a larger group, simply note from (3) that each vote becomes less pivotal, leading the expert to focus more on blame avoidance. Nonetheless, Lemma 2 indicates that blame avoidance never becomes the sole motive for voting in equilibrium since the probability of being pivotal, as well as the probability of the project's approval, remains significant in the limit.

3.2 Secret voting

Suppose now that only the committee's decision is disclosed to the outside observer. With the unanimity rule, this means that the observer would blame an expert for a No vote only when the project is rejected. And conditional on rejection and equilibrium voting, ϕ , he would believe (by Bayesian updating) that a given expert has voted No with probability $\frac{1-\phi}{1-\phi^n}$.¹³ Taking the observer's belief (and others' voting strategies) into account, expert i , therefore, accepts the project if:

$$\phi^{n-1}s_i + (1 - \phi^{n-1}) \left(-\frac{1-\phi}{1-\phi^n}b \right) > -\frac{1-\phi}{1-\phi^n}b. \quad (5)$$

Inspecting (5), note that unlike public voting, nonpivotal events also influence expert i 's strategy. In particular, under secret voting, even though the project has been rejected by someone else's vote (which occurs with probability $1 - \phi^{n-1}$), expert i shares the blame. Such blame-sharing, however, also helps the expert when his reject vote is responsible from the project's disapproval since $\frac{1-\phi}{1-\phi^n} \leq 1$. Arranging terms, (5) reduces to:

$$\phi^{n-1}s_i > \phi^{n-1} \left(-\frac{1-\phi}{1-\phi^n}b \right), \quad (6)$$

so the net effect of blame-sharing for expert i is positive at the margin and proportional to the probability of being pivotal.¹⁴ Canceling the term ϕ^{n-1} on both sides, (6) further reduces to:

$$s_i > -\frac{1-\phi}{1-\phi^n}b, \quad (7)$$

¹³We assume that experts have no credible way of communicating their votes to outside observers. In fact, to avoid blame, *all* would have an incentive to claim to have cast a Yes vote.

¹⁴These insights are not specific to the unanimity rule, as we show under general voting rules in Section 5.3.

and thus, in equilibrium, it must be that

$$\phi = 1 - F\left(-\frac{1-\phi}{1-\phi^n}b\right), \quad (8)$$

where the term $\frac{1-\phi}{1-\phi^n}b$, which is less than b , represents the effective blame in this case. Let $\phi^{SV}(n, b)$ be a solution to (8); see Figure 1.

Lemma 3 $\phi^{SV}(n, b)$ uniquely exists. Moreover, $\phi^{SV}(n, b)$ is increasing in b but decreasing in n , with $\phi^{SV}(\cdot) \rightarrow \phi_\ell(b) \in (1 - F(0), 1)$ and $(\phi^{SV}(\cdot))^n \rightarrow 0$ as $n \rightarrow \infty$.

Lemma 3 highlights the role of blame-sharing under secret voting as, unlike public voting, each expert now raises his acceptance standard toward the no-blame standard of 0 in a larger committee. More interestingly, the acceptance standard never reaches 0 (i.e., $\phi^{SV}(\cdot) > 1 - F(0)$), indicating that even in the largest committee, experts would remain concerned about social issues under secret voting. The reason is that the project is very likely to be rejected in a large committee, and each vote can be responsible from this negative outcome with a significant probability, $1 - \phi_\ell(b)$.

Combining Lemmas 2 and 3, it is evident that $\phi^{SV} \leq 1 - F(-b) \leq \phi^{PV}$, and $\frac{1-\phi^{SV}}{1-(\phi^{SV})^n}b < b \leq \frac{b}{(\phi^{PV})^{n-1}}$. That is, compared to secret voting, public voting increases the likelihood of the project's approval as well as the effective blame. Not surprisingly, this implies that the partisan observer prefers public voting to pressure the expert for a Yes vote at the margin, and in turn, the marginal type of the expert prefers secrecy to reduce such pressure and get closer to his no-blame benchmark of 0. Note, however, that the marginal type's preference for secrecy is not always shared by the infra-marginal types. In particular, an expert who has a positive signal would strictly opt for public voting to avoid any blame, which is unlikely under secret voting (unless the project is approved). To this end, it is important to also compare each expert's expected blame under the two regimes, which is, respectively, given by:

$$\phi^{PV}(0) + (1 - \phi^{PV})b = (1 - \phi^{PV})b \quad (9)$$

and

$$\left[\phi^{SV}\left(1 - (\phi^{SV})^{n-1}\right) + (1 - \phi^{SV})\right] \left(\frac{1 - \phi^{SV}}{1 - (\phi^{SV})^n}b\right) = (1 - \phi^{SV})b, \quad (10)$$

where (10) follows because under secret voting, the expert suffers from the same Bayesian blame whenever the project is rejected. From (9) and (10), it is clear that the expected blame is

proportional to one's probability of rejecting the project. Given $\phi^{SV} \leq \phi^{PV}$, this implies that while increasing the effective blame (at the margin), public voting reduces the expected blame for experts.¹⁵ Next, we examine when public voting is also the planner's optimal choice.

4 Optimal disclosure

As identified in Lemma 1, a major concern for the planner is to alleviate the negative voting externality in the committee. In particular, the planner would want the experts to lower their acceptance standards below 0 – the standard with no social issues. Lemmas 2 and 3 show that social pressure helps with this objective, but as our next result formalizes, it must be proportional to the total externality.

Lemma 4 *Fix n . Then, for disclosure regime d , there are unique levels of blame $0 < \underline{b}^d(n) < \bar{b}^d(n) < \infty$ such that the planner's welfare is strictly increasing in b for $b < \underline{b}^d(n)$, strictly decreasing in b for $\underline{b}^d(n) < b < \bar{b}^d(n)$, and constant at 0 for $b \geq \bar{b}^d(n)$.*

That is, regardless of the disclosure regime, *some* social pressure on experts is desirable by the planner. Depending on the committee size and disclosure regime, however, social pressure may be too much if it engenders a probability of acceptance higher than optimal. In principle, though, the planner cannot choose experts' preferences for blame, b , but she can amplify or diminish its effect on their decisions by the transparency of voting, as Proposition 2 indicates.

Proposition 1 *Fix n . Then, there exist unique levels of blame $0 < b_L(n) < b_M(n) < b_H(n) < \infty$ such that the planner strictly prefers public voting for $b \leq b_L(n)$, and secret voting for $b_M(n) \leq b < b_H(n)$. For $b \geq b_H(n)$, the planner is indifferent since $\phi^{PV}(n, b) = \phi^{SV}(n, b) = 1$.*

Intuitively, when experts care little about being blamed for a No vote, the planner would commit to exposing their votes so that they would further lower their acceptance standards and come closer to optimal voting. Conversely, when being blamed is already a significant concern for experts, the planner would commit to keeping their votes anonymous, so their concern is diminished, and voting is, again, brought closer to being optimal. The planner's disclosure choice depends on the signal distribution for moderate levels of blame, and it is irrelevant at very high levels, since experts avoid the blame with certainty .

¹⁵The distinction between the effective and expected blame resembles that between marginal and average tax rates: whereas the former measure the impact of taxes on incentives to earn, the latter measure tax burden.

An alternative way of understanding the planner's disclosure choice is to consider a cross-section of committee sizes, perhaps, referring to the complexity or dimensionality of projects being considered.

Proposition 2 *Suppose $\frac{b}{|s_L|} < \frac{1}{e}$. Then, there exist committee sizes $1 < n_L(b) < n_H(b) < \infty$ such that the planner strictly prefers secret voting for $n \leq n_L(b)$, and public voting for $n \geq n_H(b)$.*

Proposition 2 reveals that given the disutility from being blamed, the planner strictly prefers public voting if the committee is large enough so that the total negative externality imposed by each reject vote is also significant. And the opposite holds if the committee is sufficiently small.¹⁶ Therefore, we predict that the transparency of the voting procedure is positively correlated with the committee size or the project's complexity. From Lemmas 1 and 2, the condition, $\frac{b}{|s_L|} < \frac{1}{e}$, is also intuitive. It simply requires that under public voting, the project remains less likely to be approved than optimal even in large committees, so there is a return to increasing transparency.

When choosing the voting procedure, recall that the planner maximizes the average quality of an accepted project. In particular, perhaps having the greater society in mind, the planner is not directly concerned about the potential blame on the committee. This raises an obvious question: is there a natural tension between the planner and experts in the committee about the level of transparency? Surprisingly, we find little such tension, as Proposition 3 shows.

Proposition 3 *Let u^d denote the ex ante payoff of a representative expert under the disclosure regime d . Then, (a) $u^d = (\phi^d)^{n-1} \int_{F^{-1}(1-\phi^d)}^{s_H} s dF(s) - (1 - \phi^d)b$; (b) if the planner strictly prefers public voting, then $u^{PV} > u^{SV}$. Conversely, if $u^{SV} > u^{PV}$, then the planner strictly prefers secret voting.*

Part (a) is intuitive: compared to (2), the expected payoff of an expert is simply the planner's payoff net of the expected blame. This makes sense since the planner can also be considered as maximizing the average welfare of the committee from the project. Part (b) follows because as established above, the expected blame, $(1 - \phi^d)b$, actually diminishes under public voting. Hence, if asked before being informed, experts would unanimously endorse public voting whenever it is optimal for the planner.¹⁷ From Propositions 1 and 2, this implies that

¹⁶Proposition 2 is not immediate from Proposition 1 since the cutoff $b_L(n)$, being the intersection of two increasing functions, $\phi^o(n)$ and $\phi^{PV}(n, b)$, need not be monotonic or invertible.

¹⁷As mentioned above, if asked after being informed, experts are unlikely to support public voting unanimously.

when blame is not a significant concern or the committee is sufficiently large, both the planner and experts would agree on public voting, even though this would lead to a lower acceptance standard for the latter. To be sure, as is evident from u^d , each expert would want no blame for himself, *but* he would want the maximum blame for others so that they would all vote Yes and not be decisive. Given that blame is uniform across committee members, however, each is willing to bear some to alleviate the voting externality by others.

Overall, Proposition 3 reveals that committee members would support transparent voting as an institution. Hence, any tension between the planner and committee members is, surprisingly, for instituting secret voting. Specifically, when blame is significant or the committee is small, unlike the planner, committee members may continue to favor public voting to reduce the expected blame. But if committee members support secret voting, so would the planner, as indicated in part (b) of Proposition 3.

5 Extensions

To isolate blame avoidance as the unique source of strategic voting, and easily contrast the transparency of voting procedures, we have assumed so far: (1) an all-or-nothing disclosure regime; (2) extremely biased experts with independent private values for the project; and (3) the unanimity rule for agreement. In this section, we relax each assumption and show that our results are robust, though additional insights emerge.

5.1 Partially public voting

In practice, in addition to public and secret voting procedures, the planner may have a third, less extreme disclosure option at her disposal: partially public voting (PP), whereby individual votes are kept anonymous, but their count is revealed to the partisan observer. In this case, as with public voting, expert i continues to be a pivotal voter, and given others' strategies, ϕ , accepts the project if:

$$\phi^{n-1}s_i > \frac{b}{n}, \quad (11)$$

where the only difference from (3) is that the expert now takes a fraction of the blame since his No vote is shielded by $(n - 1)$ Yes votes.¹⁸ Hence, in equilibrium, we have

$$\phi = 1 - F\left(-\frac{b}{n\phi^{n-1}}\right). \quad (12)$$

¹⁸To see more formally how (11) obtains, let $p(j; n, \phi)$ be the binomial probability that the vote profile contains exactly j Yes votes, under which, given the symmetry, the observer believes each vote to be No with probability

Comparing (12) with (4) and (8), and noting that $\frac{1}{\phi^{n-1}} \geq \frac{1}{n\phi^{n-1}} \geq \frac{1-\phi}{1-\phi^n}$, the following proposition obtains.

Proposition 4 *There is a unique solution, $\phi^{PP}(n, b)$, to (12). Moreover, (a) $\phi^{PP}(n, b)$ is increasing in b , and either U-shaped or increasing everywhere in n ; (b) $\phi^{SV}(n, b) \leq \phi^{PP}(n, b) \leq \phi^{PV}(n, b)$; and (c) partially public voting is strictly optimal if, fixing n , the level of blame is moderate – i.e., b is sufficiently close to $b^{PP}(n)$ where $b^{PP}(n) \in (0, \infty)$ uniquely solves $\phi^{PP}(n, b) = \phi^o(n)$.*

As expected, voting incentives under partial disclosure lie between those of the two extreme disclosure regimes considered in Section 3; see Figure 2. Partial disclosure is, therefore, strictly optimal when social pressure is moderate (i.e., b close to b^{PP}), generalizing our previous conclusion in Proposition 1: the less concerned experts are about blame, the more transparent the voting procedure should be.¹⁹

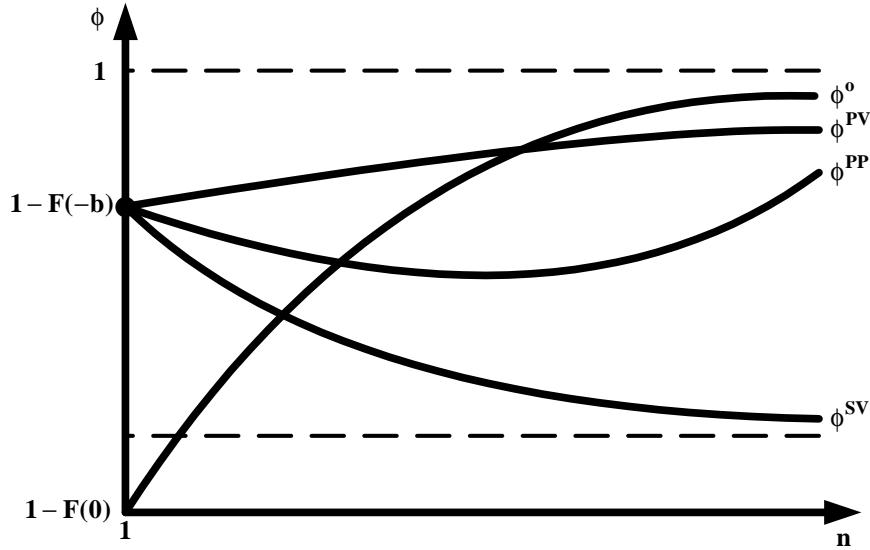


Figure 2. Partially public voting

$\frac{n-j}{n}$. Then, expert i accepts the project if:

$$\phi^{n-1}s_i + \sum_{j=0}^{n-1} p(j; n-1, \phi) \left(-\frac{n-(j+1)}{n}b\right) > \sum_{j=0}^{n-1} p(j; n-1, \phi) \left(-\frac{n-j}{n}b\right),$$

which, arranging terms and recalling that $\sum_{j=0}^{n-1} p(j; n-1, \phi) = 1$, reduces to (11).

¹⁹Since the expected blame is $(1 - \phi^{PP})b$, it is also easy to verify that Proposition 3 extends to partially public voting.

5.2 Interdependent valuations

In the base model, we have also assumed that each expert values a single aspect of the project – the one he specializes on. While such an extreme bias has helped us isolate strategic voting due purely to social issues, it is conceivable that each expert may also value other aspects of the project, which we formalize by the following interdependent valuations:²⁰

$$v_i = (1 - \alpha)s_i + \alpha \frac{\sum_j s_j}{n}, \quad (13)$$

where $\alpha \in [0, 1]$. In words, expert i 's valuation is now a convex combination of his own and others' signals, with $\alpha = 0$ referring to pure private values as in the base model and $\alpha = 1$ referring to pure common values. Hence, the parameter α captures the degree of preference "conflict" across committee members. Note, however, that the utilitarian planner's objective remains independent of α since $\sum_i v_i = \sum_i s_i$. This means that like social pressure, the planner does not directly care about the conflict in the group, and thus her optimal voting strategy found in Lemma 1 continues to apply.

To characterize the symmetric equilibria across different disclosure regimes, we proceed as in the base model and suppose that in equilibrium, each expert accepts the project with probability ϕ or equivalently, chooses a cutoff $x = F^{-1}(1 - \phi)$. Then, conditional on the pivotal event (i.e., all others' voting Yes), expert i 's expected payoff from accepting the project is:

$$E[v_i | s_i, piv] = (1 - \alpha + \frac{\alpha}{n})s_i + \alpha \frac{(n-1)E^+[F^{-1}(1 - \phi)]}{n}, \quad (14)$$

and therefore, he accepts the project if:

$$E[v_i | s_i, piv] > -B^d(\phi; n, b), \quad (15)$$

where $E^+[x] \equiv E[s | s > x]$, and $B^d(\phi; n, b) = \frac{b}{\phi^{n-1}}$ or $\frac{1-\phi}{1-\phi^n}b$ represents the effective blame for the disclosure regime $d = PV$ or SV .²¹ From (14) and (15), we can write the equilibrium condition as:

$$\phi = 1 - F\left(-\frac{\alpha \frac{(n-1)E^+[F^{-1}(1 - \phi)]}{n} + B^d(\phi; n, b)}{(1 - \alpha + \frac{\alpha}{n})}\right). \quad (16)$$

Let $\phi^d(n, b, \alpha)$ be a solution to (16).

²⁰See Moldovanu and Shi (2013) for a similar use and compelling justification of such linear interdependent payoffs in a voting environment. Interdependent payoffs are, of course, widely exploited in auction theory; see Krishna (2009).

²¹Partially public voting could be easily incorporated in this extension, but it would make a direct comparison with the base model less clear.

Lemma 5 $\phi^d(n, b, \alpha)$ uniquely exists. Moreover, $\phi^d(n, b, \alpha)$ is increasing in b and α , where both are strict if $\phi^d(\cdot) < 1$.

The symmetric equilibrium continues to be unique because the conditional mean $E^+[x]$ is increasing, and in turn, both $E^+[F^{-1}(1 - \phi)]$ and $B^d(\phi; n, b)$ are decreasing in ϕ . More interestingly, Lemma 5 identifies the preference interdependence as an additional source of strategic voting. In particular, fixing social issues, b , experts grow more likely to vote for the project, the less conflicting their preferences are – i.e., a higher α . This is because in the pivotal event with $n - 1$ Yes votes, placing more weight on others’ information, these experts hold a more positive view of the project and thus lower their own acceptance standards. Note that such softening of the acceptance standard helps correct for the negative voting externality even without social pressure. Hence, to avoid “overcorrecting” for it in the presence of social pressure, we predict that the planner would favor secret voting in committees with the least conflict and public voting in committees with the most conflict. The next proposition confirms this prediction.

Proposition 5 *If secret voting is strictly optimal for some α^* , then it is strictly optimal for $\alpha \geq \alpha^*$. Conversely, if public voting is strictly optimal for some α^{**} , then it is strictly optimal for $\alpha \leq \alpha^{**}$.*

Combining with Propositions 1 and 2, we further conclude that when experts are significantly concerned about the blame or the committee is sufficiently small, secret voting strictly dominates public voting for $\alpha = 0$, and thus for all α . Conversely, when experts are little concerned about the blame or the committee is sufficiently large, public voting strictly dominates even though experts are not total partisans – i.e., α is small but positive. Put differently, increased transparency is likely to improve the collective decision if the committee is a “team of rivals,” who are very biased toward their expertise.

5.3 Voting rule and secrecy

Our model is also special in that it fixes the consensus rule to be unanimity. In this section, we relax this assumption to understand the impact of the voting rule on the level of transparency. To this end, we first characterize the optimal voting rule in a blame-free environment, and then show that under this rule, the voting externality, and thus the planner’s need for social pressure to correct for it, is minimized, making transparency socially undesirable. Nevertheless, it is important to note that in practice, the voting rule is rarely tailored to each specific

issue, e.g., each job promotion or each legislative bill, leaving room for public voting as an institutional remedy.

To formalize our point, we begin by generalizing our baseline analysis. Suppose that the project is approved with at least k affirmative votes, i.e., by a k -majority rule, and the planner dictates the signal cutoff x for an affirmative vote. As before, let $\phi = 1 - F(x)$, or equivalently, $x = F^{-1}(1 - \phi)$. Then, the probability of a vote profile with exactly j Yes votes is binomial: $p(j; n, \phi) = \binom{n}{j} \phi^j (1 - \phi)^{n-j}$, and with this vote profile, the *ex post* expected welfare of the group from implementing the project is

$$\widehat{w}(\phi, j, n) \equiv \frac{jE^+[F^{-1}(1 - \phi)] + (n - j)E^-[F^{-1}(1 - \phi)]}{n}, \quad (17)$$

where $E^+[x] \equiv E[s|s > x]$ and $E^-[x] \equiv E[s|s < x]$ are the mean signals conditional on Yes and No votes, respectively. Given (17), the *ex ante* expected welfare is:

$$\bar{w}(\phi, k, n) \equiv \sum_{j=k}^n p(j; n, \phi) \widehat{w}(\phi, j, n). \quad (18)$$

To determine the optimal voting strategy, the planner maximizes (18) with respect to *both* k and ϕ ; that is, the planner now solves

$$\max_{k, \phi} \bar{w}(\phi, k, n). \quad (19)$$

Ignoring the (uninteresting) rounding issues with k , Lemma 6 offers a sharp characterization of (19).

Lemma 6 *The unique solution to (19) is: $\phi^o = 1 - F(0)$ and $k^o(n) = F(0) + [1 - F(0)]n$.*

To understand the planner's trade-off, we re-write (18) as (see Lemma A1):

$$\bar{w}(\phi, k, n) = p(k - 1; n - 1, \phi) \int_{F^{-1}(1 - \phi)}^{s_H} s dF(s), \quad (20)$$

which reduces to (2) for the unanimity rule, $k = n$. (20) says that the planner's payoff from the project is simply the truncated expected signal, $\int_{F^{-1}(1 - \phi)}^{\bar{\theta}} s dF(s)$, discounted by the pivot probability under a k -majority rule. It is intuitive that to avoid positive votes with negative signals, the principal would set the cutoff at $x^o = 0$, and given this cutoff, the pivot probability is maximized at the majority rule k^o . The uniqueness of the optimal solution follows from the fact that $\bar{w}(\phi, k, n)$ is single-peaked in ϕ (as with the unanimity rule) and also single-peaked in k (see Lemma A1).²²

²²The single-peakedness in ϕ is facilitated by the fact that both conditional means, $E^+[x]$ and $E^-[x]$, are increasing in x .

Compared to Lemma 1, two noteworthy features of the optimal voting strategy, ϕ^o , are that it is now independent of the committee size, n , and it coincides with an expert's (dominant) voting strategy in a blame-free environment: accept the project if $s_i > 0$ and reject it otherwise. The latter means that by optimally choosing the voting rule, the planner is able to minimize the voting externality across experts without requiring them to lower their acceptance standards. We, therefore, expect the planner to opt for secret voting under the optimal voting rule to reduce voting distortions due to social pressure.

To prove the last point, recall that under public voting, expert i is a pivotal voter, and with a k -majority rule, his vote is pivotal with probability $p(k-1; n-1, \phi)$. Hence, extending (3), expert i accepts the project if:

$$p(k-1; n-1, \phi)s_i > -b,$$

and in turn, the following condition must hold in equilibrium with public voting:

$$\phi = 1 - F\left(-\frac{b}{p(k-1; n-1, \phi)}\right). \quad (21)$$

The strategy under secret voting is more involved because there may be residual blame under a majority rule even when the project is accepted.²³ Let $\beta^A(\phi; k, n)$ and $\beta^R(\phi; k, n)$ be the expected blame shed on each expert conditional on the project's acceptance and rejection, respectively. By Bayesian updating,

$$\begin{aligned} \beta^A(\phi; k, n) &= \Pr\{i \text{ has rejected} | \text{project is accepted}\}b \\ &= \frac{(1-\phi) \sum_{j=k}^{n-1} p(j; n-1, \phi)}{\sum_{j=k}^n p(j; n, \phi)}b \end{aligned}$$

and

$$\begin{aligned} \beta^R(\phi; k, n) &= \Pr\{i \text{ has rejected} | \text{project is rejected}\}b \\ &= \frac{(1-\phi) \sum_{j=0}^{k-1} p(j; n-1, \phi)}{\sum_{j=0}^{k-1} p(j; n, \phi)}b. \end{aligned}$$

Clearly, for the unanimity rule, $\beta^A(\phi; n, n) = 0$ and $\beta^R(\phi; n, n) = \frac{1-\phi}{1-\phi^n}b$, coinciding with the base model. In general, it can be verified that $\beta^R(\phi; k, n) \geq \beta^A(\phi; k, n)$, so an expert is blamed less for a No vote when the project is accepted, as one would expect.²⁴ Defining $\beta^R(\cdot) - \beta^A(\cdot)$

²³Blaming an expert when the project is accepted may seem puzzling, but it should be interpreted as not giving him the full credit of a Yes vote under a majority rule.

²⁴Straightforward algebra shows that $\beta^R(\cdot) - \beta^A(\cdot) = \frac{\phi(1-\phi)p(k-1; n-1, \phi)}{\sum_{j=0}^{k-1} p(j; n, \phi) \sum_{j=k}^n p(j; n, \phi)}b$.

to be the effective blame, it follows that expert i accepts the project if:²⁵

$$s_i \geq - \left[\beta^R(\phi; k, n) - \beta^A(\phi; k, n) \right], \quad (22)$$

and therefore, in equilibrium with secret voting, it must be that

$$\phi = 1 - F \left(- \left[\beta^R(\phi; k, n) - \beta^A(\phi; n, n) \right] \right). \quad (23)$$

Letting $\bar{\phi}^{PV}(k, n, b)$ and $\bar{\phi}^{SV}(k, n, b)$ solve (21) and (23), respectively, Proposition 6 states our main result in this section.

Proposition 6 (a) Both $\bar{\phi}^{PV}(k, n, b)$ and $\bar{\phi}^{SV}(k, n, b)$ exist; (b) $\bar{\phi}^{PV}(\cdot) \geq \bar{\phi}^{SV}(\cdot) > 1 - F(0)$; and (c) if $k = k^o(n)$, then the planner prefers secret voting, with a strict preference whenever $\bar{\phi}^{SV}(\cdot) < 1$.

The equilibrium existence under each voting procedure is due to standard continuity arguments. Under a nonunanimity rule, however, there may be multiple equilibria.²⁶ Even so, part (b) indicates that in every equilibrium, an expert is less likely to vote for the project under secret voting, and thus create less distortion than public voting. The intuition is as in the base model with the unanimity rule: whereas public voting amplifies the effective blame shed on an expert at the margin, secret voting diminishes it – formally, $\beta^R(\phi; k, n) - \beta^A(\phi; k, n) \leq b \leq \frac{b}{p(k-1; n-1, \phi)}$. Part (c) then follows because the planner’s *ex ante* payoff, $\bar{w}(\phi, k, n)$, is single-peaked in ϕ .

Roughly, Proposition 6 says that to the extent that the planner can customize the voting rule to the specific project (since $k^o(n)$ depends on the signal distribution, F), she would keep their votes secret. Otherwise, under a suboptimal voting rule, increasing transparency can help mitigate the residual inefficiency in the committee’s decision.²⁷

6 Concluding Remarks

Transparency, committees, and voting are keywords for democratic organizations. In this paper, we have examined their relationship in a setting where committee members feel social

²⁵A detailed derivation of (22) is provided in the proof of Proposition 6.

²⁶For instance, $\bar{\phi}^{PV} = \{.53, .93, 1\}$ if $b = .1$, $(n, k) = (5, 3)$ and $s_i \sim U[-1, 1]$.

²⁷This observation can be refined further. From Remark A1 in the appendix, it readily follows that $\phi^o \leq 1 - F(0)$ for $k \leq k^o(n)$. Hence, by the single-peakedness, part (c) of Proposition 6 holds more generally for $k \leq k^o(n)$. Conversely, a suboptimal voting rule would call for public voting *only if* $k > k^o(n)$ – i.e., only if the project’s approval requires too many Yes votes. Though the exact relationship between the voting rule and transparency is elusive to us, we conjecture that all else equal, the more demanding the majority rule is, the more transparent the voting procedure would be.

pressure from partisan observers such as job candidates and patient groups to cast a favorable vote. We show that such social pressure, like taxation, can actually improve the committee's decision by correcting for a voting externality. Organizations may, therefore, advocate transparency of voting to amplify the effect of social pressure so long as it does not become too high. We find that transparency is especially preferred in large committees or those that contain overly biased members. Transparency is also preferred when the voting rule is too demanding against the alternative being considered.

In closing, we note several issues that can be fruitfully addressed within our framework. The first is the endogenous formation of the committee. In the model, we have assumed that the project has n dimensions, each of which is evaluated by one expert member. The designer may, however, trade off the number of experts, or the amount of information, against the resulting voting externality and social pressure. The second is the voluntary participation in committee meetings. It is conceivable that under social pressure, only those experts with strong opinions of the project will participate and vote, while the rest will not, to avoid blame. The incentive to participate will, however, depend crucially on the vote transparency, which would be worthwhile to investigate. Last, but not least, it would be interesting to extend our analysis to multiple observers with opposing interests, e.g., two job candidates being considered for a single position. In this case, we conjecture that blame avoidance would be more difficult, but given this, voting may be less strategic.

7 Appendix

Proof of Lemma 1. Note that $w(0, n) = w(1, n) = 0$ and $w(1 - F(0), n) > 0$, so the solution, ϕ^o , to (2) must be interior, and satisfy the following first-order condition:

$$\frac{\partial}{\partial \phi} w(\phi, n) = \phi^{n-2} \left[(n-1) \int_{F^{-1}[1-\phi]}^{s_H} s dF(s) + \phi F^{-1}(1-\phi) \right] = 0,$$

or equivalently

$$\text{FOC: } \Omega(\phi, n) \equiv (n-1) \int_{F^{-1}(1-\phi)}^{s_H} s dF(s) + \phi F^{-1}(1-\phi) = 0.$$

Next, since $F^{-1}(0) \leq s_L$ and $\int_{s_L}^{s_H} s dF(s) = 0$ by assumption, we have that $\Omega(1, n) \leq s_L < 0$. Moreover, $\Omega(1 - F(0), n) > 0$ (given $n > 1$). Hence, $\phi^o \in (1 - F(0), 1)$. This implies $F^{-1}(1 - \phi^o) < 0$, and in turn,

$$\frac{\partial^2}{\partial \phi^2} w(\phi^o, n) = \text{sign} \frac{\partial}{\partial \phi} \Omega(\phi^o, n) = n F^{-1}(1 - \phi^o) - \frac{\phi^o}{f(F^{-1}(1 - \phi^o))} < 0, \quad (\text{A-1})$$

which means that ϕ^o is unique.

Part (a) of Lemma 1 is immediate from (A-1) and the fact that $\Omega(\phi, n)$ is strictly increasing in n .

To prove part (b), suppose $\phi^o(n) \rightarrow \phi_\ell^o < 1$ as $n \rightarrow \infty$. Then, $s_L < F^{-1}(1 - \phi_\ell^o)$, which implies that $\Omega(\phi_\ell^o, n) \rightarrow \infty \neq 0$, violating the FOC. Hence, $\phi^o(n) \rightarrow 1$. Finally, to show that $(\phi^o(n))^n \rightarrow \frac{1}{e}$, we find it more convenient to write FOC:

$$(n-1) \int_{x^o}^{s_H} s dF(s) + x^o [1 - F(x^o)] = 0, \quad (\text{A-2})$$

where $x^o \equiv x^o(n) = F^{-1}(1 - \phi^o(n))$. Integrating by parts, note that

$$\int_x^{s_H} s dF(s) = x[1 - F(x)] + \int_x^{s_H} (1 - F(s)) ds, \quad (\text{A-3})$$

which, inserting into (A-2), implies

$$(n-1) \left\{ x^o [1 - F(x^o)] + \int_{x^o}^{s_H} (1 - F(s)) ds \right\} + x^o [1 - F(x^o)] = 0.$$

Arranging terms, we have

$$1 - F(x^o) = \left(\frac{n-1}{n} \right) Z(n), \quad (\text{A-4})$$

where $Z(n) \equiv -\frac{\int_{x^o}^{s_H} (1-F(s))ds}{x^o}$. Hence,

$$(\phi^o(n))^n = [1 - F(x^o)]^n = \left(\frac{n-1}{n}\right)^n (Z(n))^n, \quad (\text{A-5})$$

and in turn,

$$\begin{aligned} \lim_{n \rightarrow \infty} (\phi^o(n))^n &= \lim_{n \rightarrow \infty} \left(\frac{n-1}{n}\right)^n \lim_{n \rightarrow \infty} (Z(n))^n \\ &= \frac{1}{e} \lim_{n \rightarrow \infty} (Z(n))^n. \end{aligned} \quad (\text{A-6})$$

Note that $Z(n) \rightarrow 1$ since $x^o \rightarrow s_L$ (given $\phi^o \rightarrow 1$) and $\int_{s_L}^{s_H} (1-F(s))ds = -s_L$ (by (A-3)). This means that $\lim_{n \rightarrow \infty} (Z(n))^n = 1^\infty$ – an indeterminacy. Consider the log transformation:

$$\lim_{n \rightarrow \infty} \ln (Z(n))^n = \lim_{n \rightarrow \infty} \frac{\ln Z(n)}{1/n} = \frac{0}{0}.$$

Applying L'Hospital's rule,

$$\lim_{n \rightarrow \infty} \frac{\ln Z(n)}{1/n} = \lim_{n \rightarrow \infty} \frac{\frac{Z_n(n)}{Z(n)}}{-1/n^2}. \quad (\text{A-7})$$

Note that

$$\begin{aligned} Z_n(n) &= \frac{[1 - F(x^o)]x^o + \int_{x^o}^{s_H} (1-F(s))ds}{(x^o)^2} x_n^o \\ &= \frac{\frac{1}{n} \int_{x^o}^{s_H} (1-F(s))ds}{(x^o)^2} x_n^o \quad (\text{using (A-4)}) \\ &= \left(-\frac{x_n^o}{nx^o}\right) Z(n). \end{aligned} \quad (\text{A-8})$$

Employing (A-8), (A-7) reduces to:

$$\lim_{n \rightarrow \infty} \frac{\ln Z(n)}{1/n} = \lim_{n \rightarrow \infty} \frac{nx_n^o}{x^o}.$$

To determine $\lim_{n \rightarrow \infty} nx_n^o$, differentiate both sides of (A-4) with respect to n :

$$\begin{aligned} -f(x^o)x_n^o &= \frac{1}{n^2} Z(n) + \left(\frac{n-1}{n}\right) Z_n(n) \\ &= \frac{1}{n^2} Z(n) + \left(\frac{n-1}{n}\right) \left(-\frac{x_n^o}{nx^o}\right) Z(n) \quad (\text{using (A-8)}), \end{aligned} \quad (\text{A-9})$$

which reveals that

$$nx_n^o = \frac{\frac{1}{n} Z(n)}{\left(\frac{n-1}{n^2}\right) \frac{Z(n)}{x^o} - f(x^o)}.$$

Next, note that $nx_n^o \rightarrow 0$ since $x^o \rightarrow s_L$, $Z(n) \rightarrow 1$, and $f(s_L) > 0$ (since $f > 0$ by assumption). As a result, $\lim_{n \rightarrow \infty} \ln(Z(n))^n = 0$ or $\lim_{n \rightarrow \infty} (Z(n))^n = 1$, which reduces (A-6) to:

$$\lim_{n \rightarrow \infty} (\phi^o(n))^n = \frac{1}{e}.$$

■

Proof of Lemma 2. Re-writing (4), let $h(\phi; n, b) \equiv \phi + F\left(-\frac{b}{\phi^{n-1}}\right) - 1$. Clearly, $h(1 - F(-b); n, b) = F\left(-\frac{b}{\phi^{n-1}}\right) - F(-b) \leq 0$ and $h(1; n, b) = F(-b) \geq 0$. Hence, there is a solution, ϕ^{PV} , to $h(\phi; n, b) = 0$, and $\phi^{PV} \geq 1 - F(-b)$. Moreover, since $h(\cdot)$ is strictly increasing in ϕ , ϕ^{PV} is unique. That ϕ^{PV} is increasing in b and n follows from the fact that $h(\cdot)$ is decreasing in b and n . Next, suppose that $\phi^{PV} \rightarrow a < 1$ as $n \rightarrow \infty$. Then, $h(\phi^{PV}; n, b) \rightarrow a - 1 \neq 0$, a contradiction. Hence, $\phi^{PV} \rightarrow 1$. Finally, suppose $(\phi^{PV})^n \rightarrow c$. Given that $\phi^{PV} \rightarrow 1$, we must have from (4) that $F\left(-\frac{b}{c}\right) = 0$ and, in turn, $c \leq \frac{b}{|s_L|}$, with equality if $\frac{b}{|s_L|} < 1$. Hence, $(\phi^{PV})^n \rightarrow \min\{\frac{b}{|s_L|}, 1\}$. ■

Proof of Lemma 3. Proceeding as in the previous lemma, let

$$h(\phi; n, b) \equiv \phi + F\left(-\frac{1-\phi}{1-\phi^n}b\right) - 1.$$

Note that $h(1 - F(-b); n, b) = F\left(-\frac{1-\phi}{1-\phi^n}b\right) - F(-b) \geq 0$ (given $\frac{1-\phi}{1-\phi^n} \leq 1$), and $h(1 - F(0); n, b) = F\left(-\frac{1-\phi}{1-\phi^n}b\right) - F(0) < 0$ (given $b > 0$). Hence, there is a solution, $\phi^{SV} \in (1 - F(0), 1 - F(-b)]$, to $h(\phi; n, b) = 0$. Moreover, since $h(\cdot)$ is strictly increasing in ϕ , ϕ^{SV} is unique. To prove part (b), note that $h(\cdot)$ is decreasing in b and increasing in n , which imply that ϕ^{SV} is increasing in b and decreasing in n . Next, suppose that $\phi^{SV} \rightarrow \phi_\ell$ as $n \rightarrow \infty$. By part (a), $\phi_\ell \geq 1 - F(0)$. Moreover, $\phi_\ell < 1$; otherwise, applying L'Hospital's rule, we would find: $h(1; n, b) = F(0) \neq 0$. Then, $(\phi^{SV})^n \rightarrow 0$ and thus, ϕ_ℓ (uniquely) solves the equilibrium condition: $\phi_\ell = 1 - F(-(1 - \phi_\ell)b)$, which, given $b > 0$, reveals that $\phi_\ell > 1 - F(0)$, as desired.

■

Proof of Lemma 4. From Lemmas 2 and 3, note that $\phi^d(n, 0) = 1 - F(0) < \phi^o(n)$ (since $n > 1$) and $\phi^{PV}(n, |s_L|) = \phi^{SV}(n, n|s_L|) = 1 > \phi^o(n)$. Moreover, $\phi^d(n, b)$ is increasing in b , with strict monotonicity whenever $\phi^d(n, b) < 1$. Thus, there are unique levels of blame $0 < \underline{b}^d < \bar{b}^d < \infty$ that, respectively, solve: $\phi^d(n, b) = \phi^o(n)$ and $\phi^d(n, b) = 1$. Given the single-peakedness of $w(\phi, n)$ in ϕ by Lemma 1, the result follows. ■

Proof of Proposition 1. Let b_L , b_M , and b_H be the levels of blame that solve the respective equations: $\phi^{PV}(n, b) = \phi^o(n)$, $\phi^{SV}(n, b) = \phi^o(n)$, and $\phi^{SV}(n, b) = 1$. Since $\phi^o(n) \in (1 -$

$F(0, 1)$; $\phi^{PV}(n, 0) = 1 - F(0)$ and $\phi^{PV}(n, |s_L|) = 1$; and that $\phi^{PV}(n, b)$ is strictly increasing in b for $\phi^{PV}(n, b) < 1$, b_L uniquely exists and $b_L \in (0, |s_L|)$. Using similar arguments for $d = SV$, with the exception that $\phi^{SV}(n, n|s_L|) = 1$, b_M and b_H also uniquely exist where $b_M \in (0, n|s_L|)$ and $b_H \in (b_M, \infty)$. Since $\phi^{SV}(n, b) < \phi^{PV}(n, b)$ whenever $\phi^{SV}(n, b) < 1$, it follows that $b_L < b_H$. Furthermore, $\phi^{SV}(n, b) < \phi^{PV}(n, b) < \phi^o(n)$ for $b < b_L$; $\phi^o(n) < \phi^{SV}(n, b) < \phi^{PV}(n, b)$ for $b_M < b < b_H$; and $\phi^{SV}(n, b) = \phi^{PV}(n, b) = 1$ for $b \geq b_H$. The conclusions then follow by the single-peakedness of planner's welfare in ϕ . ■

Proof of Proposition 2. Suppose $\frac{b}{|s_L|} < \frac{1}{e}$. Ignoring the rounding issues, let n_L solve $\phi^{SV}(n, b) - \phi^o(n) = 0$. Note that $\phi^{SV}(1, b) - \phi^o(1) = F(0) - F(-b) > 0$, and from Lemma 3, $\phi^{SV}(\infty, b) - \phi^o(\infty) = \phi_\ell(b) - 1 < 0$. Moreover, $\phi^{SV}(n, b) - \phi^o(n)$ is strictly decreasing in n (since $\phi^{SV}(n, b)$ is decreasing, and $\phi^o(n)$ is strictly increasing in n). Hence, there is a unique $n_L \in (1, \infty)$ such that $\phi^o(n) \leq \phi^{SV}(n, b) < \phi^{PV}(n, b)$ for $n \leq n_L$, where the strict inequality follows because $\phi^{PV}(n, b) < 1$ for $b < |s_L|$. By the single-peakedness of $w(\phi, n)$ in ϕ , the planner, therefore, strictly prefers secret voting for $n \leq n_L$.

Next, note from Lemmas 1 and 2 that $(\phi^{PV}(n, b))^n - (\phi^o(n))^n \rightarrow \min\{\frac{b}{|s_L|}, 1\} - \frac{1}{e}$. Hence, given the assumption that $\frac{b}{|s_L|} < \frac{1}{e}$, there exists $n_H \in (n_L, \infty)$ such that $\phi^{PV}(n, b) - \phi^o(n) < 0$ for $n \geq n_H$. Furthermore, since $\phi^{SV}(n, b) < \phi^{PV}(n, b) < \phi^o(n)$ for $n \geq n_H$, the planner strictly prefers public voting under such committee sizes. ■

Proof of Proposition 3. From (3), the *ex ante* payoff of a representative expert is

$$\begin{aligned} u^{PV} &= \int_{x^{PV}}^{s_H} (\phi^{PV})^{n-1} s dF(s) + \int_{s_L}^{x^{PV}} (-b) dF(s) \\ &= (\phi^{PV})^{n-1} \int_{x^{PV}}^{s_H} s dF(s) - F(x^{PV})b \\ &= (\phi^{PV})^{n-1} \int_{F^{-1}(1-\phi^{PV})}^{s_H} s dF(s) - (1 - \phi^{PV})b. \end{aligned} \tag{A-10}$$

Similarly, from (5),

$$\begin{aligned} u^{SV} &= \int_{x^{SV}}^{s_H} \left[(\phi^{SV})^{n-1} s + (1 - (\phi^{SV})^{n-1}) \left(-\frac{1 - \phi^{SV}}{1 - (\phi^{SV})^n} b \right) \right] dF(s) \\ &\quad + \int_{s_L}^{x^{SV}} \left(-\frac{1 - \phi^{SV}}{1 - (\phi^{SV})^n} b \right) dF(s) \\ &= (\phi^{SV})^{n-1} \int_{x^{SV}}^{s_H} s dF(s) + \left\{ [1 - F(x^{SV})](1 - (\phi^{SV})^{n-1}) + F(x^{SV}) \right\} \left(-\frac{1 - \phi^{SV}}{1 - (\phi^{SV})^n} b \right) \\ &= (\phi^{SV})^{n-1} \int_{F^{-1}(1-\phi^{SV})}^{s_H} s dF(s) - (1 - \phi^{SV})b. \end{aligned} \tag{A-11}$$

Together, (A-10) and (A-11) prove part (a). To prove part (b), suppose the planner strictly prefers public voting to secret voting, i.e., using (2),

$$(\phi^{PV})^{n-1} \int_{F^{-1}(1-\phi^{PV})}^{s_H} s dF(s) > (\phi^{SV})^{n-1} \int_{F^{-1}(1-\phi^{SV})}^{s_H} s dF(s).$$

Since $\phi^{PV} > \phi^{SV}$ by Lemmas 2 and 3, we have $u^{PV} > u^{SV}$. Conversely, suppose $u^{PV} < u^{SV}$. Then, since $(1 - \phi^{PV})b < (1 - \phi^{SV})b$, we must have $(\phi^{PV})^{n-1} \int_{F^{-1}(1-\phi^{PV})}^{s_H} s dF(s) < (\phi^{SV})^{n-1} \int_{F^{-1}(1-\phi^{SV})}^{s_H} s dF(s)$, implying that the planner strictly prefers secret voting. ■

Proof of Proposition 4. Re-writing (12), let $h(\phi; n, b) \equiv \phi + F\left(-\frac{b}{n\phi^{n-1}}\right) - 1$. Clearly, $h(1 - F(0); n, b) = F\left(-\frac{b}{n\phi^{n-1}}\right) - F(0) < 0$ and $h(1; n, b) = F\left(-\frac{b}{n}\right) \geq 0$. Hence, there is a solution, $\phi^{PP} \in (1 - F(0), 1]$, to $h(\phi; n, b) = 0$. Moreover, since $h(\cdot)$ is strictly increasing in ϕ , ϕ^{PV} is unique. That ϕ^{PV} is increasing in b obtains because $h(\cdot)$ is decreasing in b . The following claim establishes part (a).

Claim A1. *If $1 - F(-b) \leq \frac{1}{e}$, then $\phi^{PP}(n, b)$ is increasing in n everywhere. If, on the other hand, $1 - F(-b) > \frac{1}{e}$, then, there is some $n^* < \infty$ such that $\phi^{PP}(n, b)$ is strictly decreasing in n for $n \leq n^*$, and strictly increasing in n for $n > n^*$.*

Proof of Claim A1. For exposition, we treat n as a continuous variable in this proof. Differentiating the equilibrium condition, $h(\phi^{PP}(n, b), n) = 0$, with respect to n :

$$\begin{aligned} \phi_n^{PP}(\cdot) &= -\frac{h_n(\phi^{PP}(n, b), n)}{h_\phi(\phi^{PP}(n, b), n)} \\ &= \text{sign} - h_n(\phi^{PP}(n, b), n) \text{ (since } h_\phi > 0) \\ &= \text{sign} - \left[1 + n \ln \phi^{PP}(n, b)\right] \end{aligned}$$

Hence, $\phi_n^{PP}(\cdot) \geq 0$ if and only if $1 + n \ln \phi^{PP}(n, b) \leq 0$, or equivalently, $\phi^{PP}(n, b) \leq e^{-1/n}$. Since $h_\phi > 0$, this implies that $h(\phi^{PP}(n, b), n) = 0 \leq h(e^{-1/n}, n)$. It is easily verified that $h(e^{-1/n}, n)$ is strictly increasing in n . As a result, $0 \leq h(e^{-1/n}, n)$ for all n if $h(e^{-1}, 1) = e^{-1} + F(-b) - 1 \geq 0$, or equivalently, $1 - F(-b) \leq \frac{1}{e}$. On the other hand, if $h(e^{-1}, 1) < 0$, then, since $h(e^{-1/n}, n) \rightarrow F(0) > 0$ as $n \rightarrow \infty$, there is a unique $n^* < \infty$ such that $h_n(\phi^{PP}(n, b), n) < 0$ (and thus, $\phi_n^{PP}(\cdot) < 0$) for $n \leq n^*$, and $h_n(\phi^{PP}(n, b), n) > 0$ (and thus $\phi_n^{PP}(\cdot) > 0$) for $n > n^*$. ■

To prove part (b), simply compare (4), (8), and (12) by observing that $\frac{1}{\phi^{n-1}} \geq \frac{1}{n\phi^{n-1}} \geq \frac{1-\phi}{1-\phi^n}$, with strict inequalities for $\phi \in (0, 1)$ given $n > 1$, and where we employ the identity: $\frac{1-\phi}{1-\phi^n} = \frac{1}{1+\dots+\phi^{n-1}}$. Finally, let $b^{PP} \in (0, \infty)$ uniquely solve: $\phi^{PP}(n, b) = \phi^o(n)$. Then, since $\phi^{SV}(n, b) < \phi^{PP}(n, b) < \phi^{PV}(n, b)$ by part (b), the single-peakedness of $w(\phi, n)$ in ϕ implies

that partially public voting is strictly optimal for the planner if $b = b^{PP}$, or by continuity, b is sufficiently close to b^{PP} , proving part (c). ■

Proof of Lemma 5. This proof is similar to those of Lemmas 2 and 3 except that the function h is now defined as:

$$h(\phi; n, b, \alpha) \equiv \phi + F \left(-\frac{\alpha \frac{(n-1)E^+[F^{-1}(1-\phi)]}{n} + B^d(\phi; n, b)}{(1 - \alpha + \frac{\alpha}{n})} \right) - 1.$$

The results then follow by noting that (1) $h_\phi(\cdot) > 0$ since $\partial E^+[F^{-1}(1-\phi)]/\partial \phi > 0$ and $\partial B^d(\phi; n, b)/\partial \phi > 0$; (2) $h_b(\cdot) \geq 0$; and (3) $h_\alpha(\cdot) \leq 0$. ■

Proof of Proposition 5. Suppose that secret voting is strictly optimal for some α^* . Then, given that $w(\phi, n)$ is single-peaked in ϕ , and $\phi^{SV}(n, b) \leq \phi^{PV}(n, b)$, one of the two conditions must hold: (I) $\phi^{PV}(\cdot, \alpha^*) > \phi^{SV}(\cdot, \alpha^*) \geq \phi^o(n)$, or (II) $\phi^{PV}(\cdot, \alpha^*) > \phi^o(n) \geq \phi^{SV}(\cdot, \alpha^*)$. Now take $\alpha \geq \alpha^*$. By Lemma 5, $\phi^{PV}(\cdot, \alpha) > \phi^{SV}(\cdot, \alpha) \geq \phi^o(n)$ under (I), so secret voting remains strictly optimal. Under (II), we either have

$$\phi^{PV}(\cdot, \alpha) \geq \phi^{PV}(\cdot, \alpha^*) > \phi^o(n) \geq \phi^{SV}(\cdot, \alpha) \geq \phi^{SV}(\cdot, \alpha^*)$$

or

$$\phi^{PV}(\cdot, \alpha) \geq \phi^{PV}(\cdot, \alpha^*) > \phi^{SV}(\cdot, \alpha) \geq \phi^o(n) \geq \phi^{SV}(\cdot, \alpha^*).$$

In each case, secret voting again remains strictly optimal. Similar arguments show that if public voting is strictly optimal for some α^{**} , then it is also strictly optimal for $\alpha \leq \alpha^{**}$. ■

Lemma A1. Let $\phi = 1 - F(x)$. Then, slightly abusing notation, the ex ante welfare stated in (18) can be simplified to:

$$\bar{w}(x, k, n) = p(k-1; n-1, x) \int_x^{SH} s dF(s).$$

Moreover, $\bar{w}(x, k, n)$ is single-peaked in x and k . In particular,

$$\bar{w}_x(x, k, n) = \text{sign} - (x + (k-1)E^+[x] + (n-k)E^-[x])$$

$$\bar{w}(x, k+1, n) - \bar{w}(x, k, n) = \text{sign} [1 - F(x)]n - k.$$

Proof. Let $\phi = 1 - F(x)$. From (18),

$$\bar{w}(x, k, n) = \sum_{j=k}^n \binom{n}{j} \phi^j (1-\phi)^{n-j} \left(\frac{jE^+[x] + (n-j)E^-[x]}{n} \right)$$

or since $E^+[x] = \frac{\int_x^{s_H} sdF(s)}{\phi}$ and $E^-[x] = \frac{\int_{s_L}^x sdF(s)}{1-\phi}$,

$$\bar{w}(x, k, n) = \sum_{j=k}^n \binom{n}{j} \phi^j (1-\phi)^{n-j} \left(\frac{j}{n} \frac{\int_x^{s_H} sdF(s)}{\phi} + \frac{n-j}{n} \frac{\int_{s_L}^x sdF(s)}{1-\phi} \right).$$

Note that $\frac{j}{n} \binom{n}{j} = \binom{n-1}{j-1}$, $\frac{n-j}{n} \binom{n}{j} = \binom{n-1}{j}$, and

$$\sum_{j=k}^n \binom{n-1}{j-1} \phi^{j-1} (1-\phi)^{n-j} = \sum_{j=k-1}^{n-1} \binom{n-1}{j} \phi^j (1-\phi)^{n-1-j}.$$

Using these identities, and noting that $E[s] = \int_x^{s_H} sdF(s) + \int_{s_L}^x sdF(s)$, we find

$$\begin{aligned} \bar{w}(x, k, n) &= \int_x^{s_H} sdF(s) \left[\sum_{j=k-1}^{n-1} \binom{n-1}{j} \phi^j (1-\phi)^{n-1-j} \right] + \int_{s_L}^x sdF(s) \left[\sum_{j=k}^{n-1} \binom{n-1}{j} \phi^j (1-\phi)^{n-1-j} \right] \\ &= E[s] \sum_{j=k}^{n-1} \binom{n-1}{j} \phi^j (1-\phi)^{n-1-j} + \int_x^{s_H} sdF(s) \left[\binom{n-1}{k-1} \phi^{k-1} (1-\phi)^{n-k} \right]. \end{aligned}$$

Since $E[s] = 0$ by assumption, we obtain the desired expression:

$$\bar{w}(x, k, n) = p(k-1; n-1, x) \int_x^{s_H} sdF(s). \quad (\text{A-12})$$

To prove the rest, simple differentiation (A-12) with respect to x reveals that

$$\begin{aligned} \bar{w}_x(x, k, n) &= -f(x) p(k-1; n-1, x) \underbrace{\left(x + (k-1)E^+[x] + (n-k)E^-[x] \right)}_{\Omega(x, k, n)} \\ &= \text{sign} - \Omega(x, k, n). \end{aligned}$$

Note that since $E^{+'}[x] > 0$ and $E^{-'}[x] > 0$, $\Omega(x, k, n)$ is strictly increasing in x ; $\Omega(s_L, k, n) = s_L + (n-k)E^-[s_L] < 0$; and $\Omega(s_H, k, n) = s_H + (k-1)E^+[s_H] > 0$, it follows that $\bar{w}(x, k, n)$ is single-peaked in x , with an interior maximum for a given k . Next, note that

$$\frac{\bar{w}(x, k+1, n)}{\bar{w}(x, k, n)} = \frac{1-F(x)}{F(x)} \frac{n-k}{k}.$$

Hence,

$$\bar{w}(x, k+1, n) - \bar{w}(x, k, n) = \text{sign} [1-F(x)] n - k,$$

which means $\bar{w}(x, k, n)$ is single-peaked in k for a given x . ■

Proof of Lemma 6. Changing variables, let (x^0, k^0) be the solution to (18), where $\phi^0 = 1 - F(x^0)$. Then, from Lemma A1 above, it is necessary that

$$x^0 + (k^0 - 1)E^+[x^0] + (n - k^0)E^-[x^0] = 0 \quad (\text{A-13})$$

and

$$[1 - F(x^o)]n \leq k^o \leq [1 - F(x^o)]n + 1. \quad (\text{A-14})$$

Suppose $k^o = [1 - F(x^o)]n$. Then, inserting this into (A-13) and using the statistical fact that $(1 - F(x))E^+[x] + F(x)E^-[x] = 0$ (since $E[s] = 0$ by assumption), (A-13) would reduce to

$$x^o - E^+[x^o] = 0,$$

whose unique solution is $x^o = s_H$. This would, however, imply $\bar{w}(x^o, k, n) = 0$, which cannot be optimal since by setting $x = 0$, the planner could do strictly better. Next, suppose $k^o = [1 - F(x^o)]n + 1$. Then, (A-13) would reduce to

$$x^o - E^-[x^o] = 0,$$

whose unique solution is $x^o = s_L$. But then, (A-12) implies $\bar{w}(x^o, k, n) = 0$, which is strictly dominated by $x > s_L$. Hence, $[1 - F(x^o)]n < k^o < [1 - F(x^o)]n + 1$. But in this region, there can at most be one integer. Let $k^o = [1 - F(x^o)]n + F(x^o)$ be this integer. Then, (A-13) becomes

$$x^o + (n - 1) \{ [1 - F(x^o)]E^+[x^o] + F(x^o)E^-[x^o] \} = 0$$

\Leftrightarrow

$$x^o + (n - 1)E[s] = 0$$

\Leftrightarrow

$$x^o = 0 \text{ (since } E[s] = 0\text{)}.$$

Hence, $k^o = [1 - F(0)]n + F(0)$, as desired. ■

Remark A1. Fixing k , suppose the planner solves: $\max_{\phi} \bar{w}(\phi, k, n)$, or equivalently $\max_x \bar{w}(1 - F(x), k, n)$. Then, using (A-13), $x^o(k)$ would uniquely solve the FOC:

$$x + (k - 1)E^+[x] + (n - k)E^-[x] = 0.$$

Since the l.h.s. is increasing in both k and x , we have that $x^o(k)$ is decreasing in k , or equivalently $\phi^o(k) = 1 - F(x^o(k))$ is increasing in k . Combining with Lemma 6, this implies that $\phi^o(k) \leq 1 - F(0)$ for $k \leq k^o(n)$, and $\phi^o(k) \geq 1 - F(0)$ for $k \geq k^o(n)$.

Proof of Proposition 6. Since parts (a) and (b) have already been established for $k = n$, we prove them for $k < n$. From (21), define

$$h(\phi) \equiv \phi + F\left(-\frac{b}{p(k-1; n-1, \phi)}\right) - 1.$$

Clearly, $h(1 - F(-b)) = F\left(-\frac{b}{p(\cdot)}\right) - F(-b) \leq 0$ and $h(1) \geq 0$. Since $h(\phi)$ is continuous in ϕ , there is a solution $\bar{\phi}^{PV}$ to $h(\phi) = 0$. Moreover, $\bar{\phi}^{PV} \geq 1 - F(-b)$.

Next, we first detail the derivation of (22). Under secret voting, expert i accepts the project if

$$\begin{aligned} & \sum_{j=k-1}^{n-1} p(j; n-1, \phi) [s_i - \beta^A(\phi; k, n)] + \sum_{j=0}^{k-2} p(j; n-1, \phi) [0 - \beta^R(\phi; k, n)] \\ & \geq \\ & \sum_{j=k}^{n-1} p(j; n-1, \phi) [s_i - \beta^A(\phi; k, n)] + \sum_{j=0}^{k-1} p(j; n-1, \phi) \times [0 - \beta^R(\phi; k, n)] \end{aligned}$$

\Leftrightarrow

$$p(k-1; n-1, \phi) [s_i - \beta^A(\phi; k, n)] \geq p(k-1; n-1, \phi) [0 - \beta^R(\phi; k, n)]$$

\Leftrightarrow

$$s_i - \beta^A(\phi; k, n) \geq -\beta^R(\phi; k, n)$$

\Leftrightarrow

$$s_i \geq -\left[\beta^R(\phi; k, n) - \beta^A(\phi; k, n)\right].$$

From (23), define

$$h(\phi) \equiv \phi + F\left(-\left[\beta^R(\phi; k, n) - \beta^A(\phi; k, n)\right]\right) - 1.$$

Next, since $0 < \beta^R(\phi; k, n) - \beta^A(\phi; k, n) \leq b$, we have that $h(1 - F(0)) < 0$ and $h(1 - F(-b)) \geq 0$. Hence, by continuity of $h(\phi)$, there is a solution, $\bar{\phi}^{SV}$ to $h(\phi) = 0$. Moreover, $\bar{\phi}^{SV} \in (1 - F(0), 1 - F(-b)]$. Together, we conclude that for any k ,

$$1 - F(0) < \bar{\phi}^{SV} \leq 1 - F(-b) \leq \bar{\phi}^{PV}. \quad (\text{A-15})$$

To prove part (c), recall from Lemma 6 that $\phi^o = 1 - F(0)$. Hence, by (A-15) and the single-peakedness of $\bar{w}(\phi, k, n)$ in ϕ , it follows that

$$\bar{w}(\bar{\phi}^{SV}, k^o, n) \geq \bar{w}(\bar{\phi}^{PV}, k^o, n),$$

with strict inequality for $\bar{\phi}^{SV} < 1$. ■

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