TRANSPARENCY OF DELIBERATIONS

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Abstract

Gilat Levy (2007a, *AER*) has argued that when experts are primarily motivated by career concerns, sometimes the decision maker is better off not to announce individual or collective votes recommending ideal actions but rather announce only the final decision (for an appropriately chosen voting rule). That is, *secrecy* may outperform *transparency*. If experts can be asked by the decision maker to vote in sequence (as opposed to Levy's simultaneous voting), it is shown that *semi-transparency*, where only collective votes are announced but not their timing, weakly dominates both *secrecy* and *complete transparency* (where individual votes and their timing are announced). This result is shown in a Bayesian decision making setting (with experts motivated by career concerns), rather than for specific voting rules.
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1 Introduction

Decision making procedures influence the advice given by experts motivated by career concerns. For any given voting rule (say, an $x\%$ rule to select a decision), voting strategies depend on whether individual experts' votes are made public or remain secret with only the aggregate decision announced. Gilat Levy (2007a,b) has argued that with secretive voting experts are more likely to conform to pre-existing biases (either in the voting rule or in the prior), while transparency often leads to contrarian voting. Conformity under secrecy allows one to put the blame on others if the decision chosen goes wrong, whereas by voting "the other way" under transparency one can appear smart. In both papers, Levy assumed simultaneous voting. In this paper, we consider sequential recommendation by two experts according to an exogenous order chosen by the decision maker, who then makes the optimal decision in a Bayesian manner (rather than, according to a specific voting rule). Our main result is that a *semi-transparent* procedure where experts' collective recommendations are made public without revealing who made what recommendation when leads to revelation of the experts' signals and is better than both *complete transparency* (with recommenders' identities and the recommendation sequence revealed) and *secrecy* (where only the final decision is announced).

To understand why an intermediate level of transparency might be an ideal environment for information revelation, one has to go back to one of Levy's reasons why sometimes secrecy is better: with transparency one is inclined to vote against the prior bias and this distortion is negated under secrecy.

2 Model

Consider the following game. There are two experts $i \in \{1, 2\}$, one decision maker D, and one outside observer O. There are two states of the world, $\omega \in \{a, b\}$. All players have a common prior $\Pr(a) = q$ where $q \in \left[\frac{1}{2}, 1\right)$. So, the prior favors the state a. Expert i receives a signal $s_i \in \{\alpha, \beta\}$. The joint distribution of signal and state, given expert i's type $t_i \in \{\xi, \lambda\}$, is as follows:

Table 1: Joint distribution of signal and state

	a	b
α	qt_i	$(1-q)(1-t_i)$
β	$q(1-t_i)$	$(1-q)t_i$

As is normally understood, type denotes the quality of an expert's signal: $\Pr(s_i = \alpha \mid \omega = a) = \Pr(s_i = \beta \mid \omega = b) = t_i$. An expert infers the state from his signal using Bayesian updating, e.g., $\Pr(\omega = a \mid s_i = \alpha, t_i) = \frac{qt_i}{qt_i+(1-q)(1-t_i)}$. We assume that the distribution of the experts' signals conditional on the state are independent. Further, types are i.i.d., with $\Pr(t_i = \lambda) = \theta$ for $i = 1, 2$.

For later computations, below we report the joint distribution over state, signals and expert types. Given our assumption on independence (of both signals and types), we have (to facilitate reading we divide the distribution into two tables, and for only the following tables let $q' = (1-q)$):

Table 2: Joint distribution of state, signals and types

	$t_1 = \lambda, t_2 = \lambda$	$t_1 = \lambda, t_2 = \xi$	$t_1 = \xi, t_2 = \lambda$	$t_1 = \xi, t_2 = \xi$
a, α, α	$q\theta^2\lambda^2$	$q\theta(1-\theta)\lambda\xi$	$q\theta(1-\theta)\lambda\xi$	$q(1-\theta)^2\xi^2$
a, α, β	$q\theta^2\lambda(1-\lambda)$	$q\theta(1-\theta)\lambda(1-\xi)$	$q\theta(1-\theta)\xi(1-\lambda)$	$q(1-\theta)^2\xi(1-\xi)$
a, β, α	$q\theta^2\lambda(1-\lambda)$	$q\theta(1-\theta)(1-\lambda)\xi$	$q\theta(1-\theta)(1-\xi)\lambda$	$q(1-\theta)^2(1-\xi)\xi$
a, β, β	$q\theta^2(1-\lambda)^2$	$q\theta(1-\theta)(1-\lambda)(1-\xi)$	$q\theta(1-\theta)(1-\xi)(1-\lambda)$	$q(1-\theta)^2(1-\xi)^2$

Table 3: Joint distribution of state, signals and types

	$t_1 = \lambda, t_2 = \lambda$	$t_1 = \lambda, t_2 = \xi$	$t_1 = \xi, t_2 = \lambda$	$t_1 = \xi, t_2 = \xi$
b, α, α	$q'\theta^2(1-\lambda)^2$	$q'\theta(1-\theta)(1-\lambda)(1-\xi)$	$q'\theta(1-\theta)(1-\xi)(1-\lambda)$	$q'(1-\theta)^2(1-\xi)^2$
b, α, β	$q'\theta^2\lambda(1-\lambda)$	$q'\theta(1-\theta)(1-\lambda)\xi$	$q'\theta(1-\theta)(1-\xi)\lambda$	$q'(1-\theta)^2(1-\xi)\xi$
b, β, α	$q'\theta^2\lambda(1-\lambda)$	$q'\theta(1-\theta)\lambda(1-\xi)$	$q'\theta(1-\theta)\xi(1-\lambda)$	$q'(1-\theta)^2\xi(1-\xi)$
b, β, β	$q'\theta^2\lambda^2$	$q'\theta(1-\theta)\lambda\xi$	$q'\theta(1-\theta)\lambda\xi$	$q'(1-\theta)^2\xi^2$

All of the above are common knowledge. Each expert privately observes his signal and is privately informed about his type. An expert i is randomly drawn by D, with some non-degenerate probability, to move first. He casts a vote $v_i^1 \in \{A, B\}$ (subscript denotes the expert and superscript denotes the timing of his move.) The vote is seen by D and the second expert. The expert j then moves and casts a vote $v_j^2 \in \{A, B\}$ which is also observed by D. (Thus, whenever we need to distinguish the experts by the timing of their moves, we will denote the first mover by index i and the second mover by index j. Also, sometimes i, j are used as ordinary labels for experts.)

Let the vote profile (v_i^1, v_j^2) be denoted by v, where $v \in V \equiv \{A, B\} \times \{A, B\}$.

After D makes the decision, the *true* state is revealed and D receives a payoff $\pi_D(d, \omega)$, where

$$\pi_D(A, a) = \pi_D(B, b) = 1, \tag{1}$$

$$\pi_D(B, a) = \pi_D(A, b) = 0. \tag{2}$$

The decision maker D uses a **Bayesian decision rule** $d : V \to \{A, B\}$. Roughly speaking, D processes the information about the underlying state from the experts' recommendations/votes, including the timing of votes, knowing that the experts are motivated by how they are perceived by outsiders as able observers of the state. Based on the information gathered applying Bayesian updating to the recommendations (together with the experts' strategies and her own strategy), D will choose a decision that is more likely to correspond with the state.

Observer O has no action and attaches no intrinsic value to (d, ω) pairs. However, the observer is interested in learning about the experts' types perhaps because she might hire one in some capacity in the future. Alternatively, the observer may be considered to be an anonymous "playing field for experts" whereupon the experts want to make an impression.[1] Like in Levy (2007a), each expert's payoff depends on O's expectation of the particular expert's type.[2] These expectations depend on what O observes. Let O observe the realized state of the world and the decision taken by D. We consider three cases which depend on what else is observed by O. The following assumption will be maintained throughout the paper.

Assumption 1 (Threshold on expertise)**.** $1 > \lambda > \xi > q \geq 1/2$.

That is, even the "low" type expert's signal is more informative than the unrefined (prior) information available to D. If the low type were to receive signal β, *his signal's value would not be washed out by a strong prior in favor of a in the sense that he would always vote his signal if this was his only piece of evidence (see (7) and the follow-up remark)*. The assumption is unlike that in Levy (2007a), where the bulk of action takes place because it may be the case that $q > \xi$. We abstract from complications caused by potentially "weak" experts (who would always agree with D) to highlight the role played by sequential voting. However, as we will see in section 3, sequential voting will endogenously affect the posterior beliefs of the second voter. As in herds, the information content of the second voter's signal may then be washed out by the first voter's vote. It is useful to define k, though we shall use this notation only later on:

$$k \equiv \theta\lambda + (1 - \theta)\xi.$$

It is clear that $\lambda > k > \xi$. Assumption 1 also implies Fact 1 (as λ and ξ are strictly greater than q and $1/2$).

[1] In political debates a politician wants to impress fellow politicians or the party leader about his predictive ability and insights by arguing in favor of certain policies; in corporate board meetings junior managers may suggest appropriate marketing strategies to their division chief to outsmart a rival firm; and so on.

[2] This is not a contest game where payoff to a player is decreasing in rivals' performance. So the experts do not directly compete with each other.

Fact 1. $\frac{\lambda}{1-\lambda} > \frac{k}{1-k} > \frac{\xi}{1-\xi} > \frac{q}{1-q} \geq 1.$

(What is the role of Fact 1, do we state it briefly?)

We now specify the various cases.

Case 1. ***[Semi-transparency]*** O observes the summary votes cast by the experts but does not observe who cast what votes. Nor does she observe who moved first and who moved second. Thus she can observe whether two, one or zero votes have been cast in favor of A. We denote the summary votes as nA where n is either 2, 1 or 0. Thus O observes a realization of the outcome, (nA, d, ω), and Bayes-updates her beliefs regarding the experts' types denoted by $\Pr(t_i \mid nA, d, \omega)$. The expected type of i is then

$$E(t_i|nA, d, \omega) = \Pr(t_i = \lambda \mid nA, d, \omega)\lambda + \Pr(t_i = \xi \mid nA, d, \omega)\xi. \tag{3}$$

This then is expert i's payoff associated with the outcome (nA, d, ω).

Case 2. ***[Complete transparency]*** O observes the sequence of moves (which expert moves first and which second) as well as the votes cast by the experts. In particular, O observes a realization of the outcome, $(v_i^1, v_j^2, d, \omega)$, and Bayes-updates her beliefs regarding the experts' types denoted by $\Pr(t_i \mid v_i^1, v_j^2, d, \omega)$. The expected types of i and j, and hence their payoffs, are

$$\begin{aligned} E(t_i|v_i^1, v_j^2, d, \omega) &= \Pr(t_i = \lambda \mid v_i^1, v_j^2, d, \omega)\lambda + \Pr(t_i = \xi \mid v_i^1, v_j^2, d, \omega)\xi \\ E(t_j|v_i^1, v_j^2, d, \omega) &= \Pr(t_j = \lambda \mid v_i^1, v_j^2, d, \omega)\lambda + \Pr(t_j = \xi \mid v_i^1, v_j^2, d, \omega)\xi. \end{aligned} \tag{4}$$

Case 3. ***[Secrecy]*** O only observes a realization of the outcome, (d, ω), and Bayes-updates to $\Pr(t_i \mid d, \omega)$. The expected type of i, and hence his payoff, is

$$E(t_i|d, \omega) = \Pr(t_i = \lambda \mid d, \omega)\lambda + \Pr(t_i = \xi \mid d, \omega)\xi. \tag{5}$$

Case 4. ***[(Levy) transparency]*** O observes the votes cast by each expert but not the timing of votes so that the relevant outcome is (v_i, v_j, d, ω) and Bayes-updates her beliefs regarding the experts' types denoted by $\Pr(t_i \mid v_i, v_j, d, \omega)$. The expected types of i and j, and hence their payoffs, are

$$\begin{aligned} E(t_i|v_i, v_j, d, \omega) &= \Pr(t_i = \lambda \mid v_i, v_j, d, \omega)\lambda + \Pr(t_i = \xi \mid v_i, v_j, d, \omega)\xi \\ E(t_j|v_i, v_j, d, \omega) &= \Pr(t_j = \lambda \mid v_i, v_j, d, \omega)\lambda + \Pr(t_j = \xi \mid v_i, v_j, d, \omega)\xi. \end{aligned} \tag{6}$$

This completes the description of all our games. The concept of equilibrium is that of *Perfect Bayesian Equilibrium.*

We start by analyzing Cases 1 and 2. Case 3 will be dealt with in section 4.

3 When voting reveals signals

Our analysis from here onwards will focus on the key question of how different forms of transparency of deliberations in decision making lead to experts revealing (or not revealing) their signals. For an optimal decision to correspond with the state, the only information D is going to rely on are the experts' recommendations. Since experts' types are private information, recommendations are useful in learning about the state so long as those reflect the experts' signals. The outsider will try to infer the quality of experts' signals (i.e. the experts' quality) by comparing the recommendations against the realized state. The experts will therefore strategically communicate their signals either by making truthful recommendations or by recommending different from what their own signals suggest, whichever helps them to project as high-quality experts.

We start by analyzing the experts' beliefs about the underlying state when both experts are assumed to reveal their signals, by voting their respective signals.[3] That is, when an expert's signal is α he votes A, and when the signal is β he votes B.

Consider expert i who moves first. His beliefs conditional on his type and signal are given by $\Pr(\omega \mid s_i^1, t_i)$ as follows (refer Table 1):

$$\begin{aligned}
\Pr(a \mid \alpha, t_i) &= \tfrac{qt_i}{qt_i+(1-q)(1-t_i)} &> \tfrac{1}{2} \\
\Pr(b \mid \alpha, t_i) &= \tfrac{(1-q)(1-t_i)}{qt_i+(1-q)(1-t_i)} &< \tfrac{1}{2} \\
\Pr(a \mid \beta, t_i) &= \tfrac{q(1-t_i)}{q(1-t_i)+(1-q)t_i} &< \tfrac{1}{2} \\
\Pr(b \mid \beta, t_i) &= \tfrac{(1-q)t_i}{q(1-t_i)+(1-q)t_i} &> \tfrac{1}{2}\,.
\end{aligned} \tag{7}$$

The inequalities follow from Assumption 1 and Fact 1. Note that despite the bias in prior belief in favor of state a ($q > \frac{1}{2}$), signal β reverses this belief for either type of expert.

Next consider expert j who moves second. Assuming that the expert who moves first votes his signal, the second expert updates his beliefs conditional on (s_i^1, s_j^2, t_j), using Tables 2 and 3, as follows (Assumption 1 and Fact 1 are used to establish the inequalities):

$$\begin{aligned}
\Pr(a \mid \alpha, \alpha, t_j) &= \tfrac{qt_j(\theta\lambda+(1-\theta)\xi)}{qt_j(\theta\lambda+(1-\theta)\xi)+(1-q)(1-t_j)(1-\theta\lambda-(1-\theta)\xi)} &> \tfrac{1}{2} \\
\Pr(b \mid \alpha, \alpha, t_j) &= \tfrac{(1-q)(1-t_j)(1-\theta\lambda-(1-\theta)\xi)}{qt_j(\theta\lambda+(1-\theta)\xi)+(1-q)(1-t_j)(1-\theta\lambda-(1-\theta)\xi)} &< \tfrac{1}{2} \\
\Pr(a \mid \beta, \beta, t_j) &= \tfrac{q(1-t_j)(1-\theta\lambda-(1-\theta)\xi)}{(1-q)t_j(\theta\lambda+(1-\theta)\xi)+q(1-t_j)(1-\theta\lambda-(1-\theta)\xi)} &< \tfrac{1}{2} \\
\Pr(b \mid \beta, \beta, t_j) &= \tfrac{(1-q)t_j(\theta\lambda+(1-\theta)\xi)}{(1-q)t_j(\theta\lambda+(1-\theta)\xi)+q(1-t_j)(1-\theta\lambda-(1-\theta)\xi)} &> \tfrac{1}{2} \\
\Pr(a \mid \beta, \alpha, t_j) &= \tfrac{qt_j(1-\theta\lambda-(1-\theta)\xi)}{qt_j(1-\theta\lambda-(1-\theta)\xi)+(1-q)(1-t_j)(\theta\lambda+(1-\theta)\xi)} &> \tfrac{1}{2} \\
\Pr(b \mid \beta, \alpha, t_j) &= \tfrac{(1-q)(1-t_j)(\theta\lambda+(1-\theta)\xi)}{qt_j(1-\theta\lambda-(1-\theta)\xi)+(1-q)(1-t_j)(\theta\lambda+(1-\theta)\xi)} &< \tfrac{1}{2} \\
\Pr(a \mid \alpha, \beta, t_j) &= \tfrac{q(1-t_j)(\theta\lambda+(1-\theta)\xi)}{q(1-t_j)(\theta\lambda+(1-\theta)\xi)+(1-q)t_j(1-\theta\lambda-(1-\theta)\xi)} & \\
\Pr(b \mid \alpha, \beta, t_j) &= \tfrac{(1-q)t_j(1-\theta\lambda-(1-\theta)\xi)}{q(1-t_j)(\theta\lambda+(1-\theta)\xi)+(1-q)t_j(1-\theta\lambda-(1-\theta)\xi)}\,. &
\end{aligned} \tag{8}$$

[3] This, of course, need not be true in equilibrium.

Unlike the rest, the last two probabilities can fall on either side of 1/2. Note that when the second expert observes a contrarian signal and which also happens to be different from the first expert's signal, it is not clear which information – own or the other expert's signal – should dominate.

3.1 D's optimal decision under semi-transparency

When voting reveals signals, D's optimal decision will not be relevant for O's assessment of expert types. However, for later use we calculate D's posteriors on the state and derive a lemma regarding the optimal decision. For vote profiles (A, A), (A, B), (B, A) and (B, B), D knows that the corresponding signals are (α, α), (α, β), (β, α) and (β, β). D's posteriors are then:[4]

$$\begin{array}{rclcl} \Pr(\omega = a \mid A, A) = & \frac{q(\theta\lambda+(1-\theta)\xi)^2}{q(\theta\lambda+(1-\theta)\xi)^2+(1-q)(1-\theta\lambda-(1-\theta)\xi)^2} & > & \frac{1}{2} \\ \Pr(\omega = a \mid B, A) = & q & \geq & \frac{1}{2} \\ \Pr(\omega = a \mid A, B) = & q & \geq & \frac{1}{2} \\ \Pr(\omega = a \mid B, B) = & \frac{(1-q)(1-\theta\lambda-(1-\theta)\xi)^2}{q(\theta\lambda+(1-\theta)\xi)^2+(1-q)(1-\theta\lambda-(1-\theta)\xi)^2} & < & \frac{1}{2}\,. \end{array} \tag{9}$$

We have the following lemma:

Lemma 1. *Consider the case when voting reveals signals. If $q > \frac{1}{2}$, D selects B if only if two votes are cast in favor of B; otherwise D selects A. When $q = \frac{1}{2}$, D is indifferent between A and B when only one vote is cast in favor of A; otherwise D selects the alternative voted by both the experts.*

3.2 Full revelation under semi-transparency

Below we are going to argue that under semi-transparency the experts will truthfully reveal their signals. Usually, under sequential voting, herding makes information aggregation problematic. But if the voting sequence is *not* disclosed, the pressure of herding is likely to be negated.[5] Now the experts' main concern would be to create a positive impression of their collective ability. But why a supposedly low-ability expert, having seen a vote that corresponds with the prior bias, is not to be tempted to ignore his own contrarian signal and herd in order to improve the outsider's belief on experts' collec-

[4] To calculate these probabilities we can use Tables 2 and 3. For example consider $\Pr(\omega = a \mid A, A)$. Since experts reveal their signals, $\Pr(\omega = a \mid A, A) = \Pr(\omega = a \mid \alpha, \alpha)$. This probability is a ratio where the numerator is the sum of all columns entries in row two of Table 2. In the denominator we have this sum plus the sum of all columns entries in row two of Table 3. This ratio is q. The other probabilities can be derived similarly. (Check this footnote for accuracy.)

[5] With more than two experts, a case that we consider briefly later in the paper, there is going to be some herding down the chain, but even there it can be shown that the maximum information revelation will occur under semi-transparency.

tive ability is still not very clear. We aim to clarify the intuitions for this apparently non-intuitive result side-by-side the formal arguments.

Let us first estimate O's beliefs about the experts' types. Since collective votes are announced and the votes reveal signals (by hypothesis), O can ignore D's decision and calculate her posteriors from the fundamental distributions given in Tables 2 and 3, as follows:[6]

$$\begin{array}{rrc}
\Pr(t=\lambda \mid 2A,a) = & \Pr(t=\lambda \mid 0A,b) = & \frac{\theta\lambda}{\theta\lambda+(1-\theta)\xi} \\
\Pr(t=\xi \mid 2A,a) = & \Pr(t=\xi \mid 0A,b) = & \frac{(1-\theta)\xi}{\theta\lambda+(1-\theta)\xi} \\
\Pr(t=\lambda \mid 2A,b) = & \Pr(t=\lambda \mid 0A,a) = & \frac{\theta(1-\lambda)}{\theta(1-\lambda)+(1-\theta)(1-\xi)} \\
\Pr(t=\xi \mid 2A,b) = & \Pr(t=\xi \mid 0A,a) = & \frac{(1-\theta)(1-\xi)}{\theta(1-\lambda)+(1-\theta)(1-\xi)} \\
\Pr(t=\lambda \mid 1A,a) = & \Pr(t=\lambda \mid 1A,b) = & \theta \\
\Pr(t=\xi \mid 1A,a) = & \Pr(t=\xi \mid 1A,b) = & 1-\theta.
\end{array} \tag{10}$$

Note that the beliefs, for any given pair of votes, are identical for both experts, given that O does not observe the sequence of moves.

Thus when O sees two A votes (zero A vote) and the state is revealed as a (b), her expectation of either expert's type is

$$\frac{\theta\lambda}{\theta\lambda+(1-\theta)\xi}\lambda + \frac{(1-\theta)\xi}{\theta\lambda+(1-\theta)\xi}\xi = \frac{\theta\lambda}{k}\lambda + \frac{(1-\theta)\xi}{k}\xi. \tag{11}$$

This "expected type" is higher than the "prior expected type," the latter being $\theta\lambda+(1-\theta)\xi$. So this is beneficial to the experts. However, when O sees two A votes (zero A vote) and the state is revealed as b (a), the experts loose out as O's expectation now is:

$$\frac{\theta(1-\lambda)}{1-\theta\lambda-(1-\theta)\xi}\lambda + \frac{(1-\theta)(1-\xi)}{1-\theta\lambda-(1-\theta)\xi}\xi = \frac{\theta(1-\lambda)}{1-k}\lambda + \frac{(1-\theta)(1-\xi)}{1-k}\xi. \tag{12}$$

When O sees only one A vote, she learns nothing more about the experts' types. The expected type remains the same as the prior expected type:

$$\Pr(\lambda \mid 1A,a)\lambda + \Pr(\xi \mid 1A,a)\xi = \theta\lambda+(1-\theta)\xi. \tag{13}$$

We now look at the experts' payoffs and the optimal strategies. We start with expert j who votes second. If he casts a vote contrary to the first-period vote, then the outcome

[6] To calculate these posteriors consider, for example, $\Pr(t=\lambda \mid 2A,a)$. Since a is the revealed state of the world, we confine ourselves to that part of the distribution in Table 2. With $2A$ being the summary votes, we consider only row one. Then $\Pr(t=\lambda \mid 2A,a)$ is the ratio of the sum of elements in the first two columns to the sum of elements in all the columns. This gives us

$$\frac{q\theta^2\lambda^2+q\theta(1-\theta)\lambda\xi}{q\theta^2\lambda^2+q\theta(1-\theta)\lambda\xi+q\theta(1-\theta)\lambda\xi+q(1-\theta)^2\xi^2} = \frac{\theta\lambda[\theta\lambda+(1-\theta)]}{\theta\lambda[\theta\lambda+(1-\theta)]+(1-\theta)\xi[\theta\lambda+(1-\theta)]} = \frac{\theta\lambda}{\theta\lambda+(1-\theta)\xi}.$$

for O is $(1A, \omega)$. Hence, irrespective of his signal or type, the expert's payoff is as in (13).

Alternatively, if j votes the same as the first-period vote, his expected payoff can be written as

$$\Pr(\omega = v \mid s_i^1, s_j^2, t_j) \underbrace{\left[\frac{\theta\lambda}{k}\lambda + \frac{(1-\theta)\xi}{k}\xi\right]}_{>(13)} + \Pr(\omega \neq v \mid s_i^1, s_j^2, t_j) \overbrace{\left[\frac{\theta(1-\lambda)}{1-k}\lambda + \frac{(1-\theta)(1-\xi)}{1-k}\xi\right]}^{<(13)}, \tag{14}$$

where $\omega = v$ denotes the vote matching the revealed state and $\omega \neq v$ denotes otherwise. Compared to the case of opposite recommendations, uniform recommendation by the experts will augment their payoffs if the recommended choice matches the state but lower the payoffs if the state differs from the recommended alternative. So whether the second expert makes the same recommendation (as the first expert) or not will depend on his beliefs about the state.

This expression (14) can be rewritten as

$$\left[\Pr(\omega = v \mid .)\frac{\theta\lambda}{k} + \Pr(\omega \neq v \mid .)\frac{\theta(1-\lambda)}{1-k}\right]\lambda + \left[\Pr(\omega = v \mid .)\frac{(1-\theta)\xi}{k} + \Pr(\omega \neq v \mid .)\frac{(1-\theta)(1-\xi)}{1-k}\right]\xi. \tag{15}$$

Interpretation. *The second expert believes that if he were to vote the same way as the first expert, the outside observer would view him as:*

- *type* λ *with probability* $\left[\Pr(\omega = v \mid .)\frac{\theta\lambda}{k} + \Pr(\omega \neq v \mid .)\frac{\theta(1-\lambda)}{1-k}\right]$;
- *type* ξ *with probability* $\left[\Pr(\omega = v \mid .)\frac{(1-\theta)\xi}{k} + \Pr(\omega \neq v \mid .)\frac{(1-\theta)(1-\xi)}{1-k}\right]$.

Note that these probabilities depend not only on O*'s ex-post beliefs, but also on the expert's own beliefs after observing the first-period vote. It is clear that if*

$$\left[\Pr(\omega = v \mid .)\frac{\theta\lambda}{k} + \Pr(\omega \neq v \mid .)\frac{\theta(1-\lambda)}{1-k}\right] > \theta,$$

the second expert would vote the same way as the first expert. Otherwise he would cast a contrarian vote.

The second expert will have the least incentive to vote truthfully if his signal is different from one corresponding to the state favored by the prior as well as the first expert's vote (and the signal). This is when the incentive to herd is the strongest. Below we first show that this type of herding will not happen. Then, in the Appendix, we rule out other variants of non-truthful voting by the second expert.

Suppose the second expert, j, observes signal β and sees a first-period vote A. If he also votes A, he receives

$$
\begin{aligned}
& \pi_j(A,\alpha,\beta,t_j) \\
= \;& \Pr(a \mid \alpha,\beta,t_j)\left[\frac{\theta\lambda}{k}\lambda+\frac{(1-\theta)\xi}{k}\xi\right]+\Pr(b \mid \alpha,\beta,t_j)\left[\frac{\theta(1-\lambda)}{1-k}\lambda+\frac{(1-\theta)(1-\xi)}{1-k}\xi\right] \\
= \;& \left[\frac{q(1-t_j)\lambda+(1-q)t_j(1-\lambda)}{q(1-t_j)k+(1-q)t_j(1-k)}\right]\theta\lambda+\left[\frac{q(1-t_j)\xi+(1-q)t_j(1-\xi)}{q(1-t_j)k+(1-q)t_j(1-k)}\right](1-\theta)\xi, \quad (16)
\end{aligned}
$$

whereas by voting B he receives $\pi_j(B,\alpha,\beta,t_j)=\theta\lambda+(1-\theta)\xi$.

It is easy to check that the weights associated with λ and ξ add up to one. Now, note that as $\lambda > k$,

$$
\begin{aligned}
& \frac{q(1-t_j)\lambda+(1-q)t_j(1-\lambda)}{q(1-t_j)k+(1-q)t_j(1-k)} < 1 \\
\Leftrightarrow \;& q(1-t_j)(\lambda-k) < (1-q)t_j(\lambda-k) \\
\Leftrightarrow \;& \frac{t_j}{1-t_j} > \frac{q}{1-q},
\end{aligned}
$$

which is true by Fact 1. So, the second expert will vote his signal when he sees a first-period vote of A and had himself observed signal β.

Intuition. *Since $\frac{t_j}{1-t_j} > \frac{q}{1-q}$, even a low-type expert is reasonably well-informed. That is, if he observes a signal β he believes that state b is going to occur with a probability greater than q. When he sees a first-period vote of A, he does update in favor of state a. But the resulting posterior is not high enough for him to expect that O will view him as type λ with a probability greater than θ.*

We now consider expert i, who votes first. To ease the exposition, let

$$
\begin{aligned}
x &\equiv \frac{\theta\lambda}{\theta\lambda+(1-\theta)\xi}\lambda+\frac{(1-\theta)\xi}{\theta\lambda+(1-\theta)\xi}\xi, \\
y &\equiv \frac{\theta(1-\lambda)}{\theta(1-\lambda)+(1-\theta)(1-\xi)}\lambda+\frac{(1-\theta)(1-\xi)}{\theta(1-\lambda)+(1-\theta)(1-\xi)}\xi, \\
H(t_i) &\equiv qt_ik+(1-q)(1-t_i)(1-k)+qt_i(1-k)+(1-q)(1-t_i)k = \Pr(s_i=\alpha_i).
\end{aligned}
$$

Due to Assumption 1,

$$
x > k > y. \quad (17)
$$

Suppose expert i has observed signal α. If i votes A then, given that j votes his signal, i's payoff is

$$
\pi_i(A,\alpha,t_i)=\frac{qt_ik}{H(t_i)}x+\frac{(1-q)(1-t_i)(1-k)}{H(t_i)}y+\frac{qt_i(1-k)+(1-q)(1-t_i)k}{H(t_i)}k.
$$

If i votes B, his payoff is

$$\pi_i(B,\alpha,t_i) = \frac{(1-q)(1-t_i)k}{H(t_i)}x + \frac{qt_i(1-k)}{H(t_i)}y + \frac{qt_ik + (1-q)(1-t_i)(1-k)}{H(t_i)}k.$$

Now,

$$\pi_i(A,\alpha,t_i) > \pi_i(B,\alpha,t_i)$$

as,

$$\begin{aligned} & (qt_ik)x + (1-q)(1-t_i)(1-k)y + (qt_i(1-k) + (1-q)(1-t_i)k)k \\ > \; & ((1-q)(1-t_i)k)x + qt_i(1-k)y + (qt_ik + (1-q)(1-t_i)(1-k))k \end{aligned}$$

as,

$$\begin{aligned} & (qt_ik)(x-k) + (1-q)(1-t_i)(1-k)(y-k) \\ > \; & ((1-q)(1-t_i)k)(x-k) + qt_i(1-k)(y-k) \end{aligned}$$

as,

$$(qt_i - (1-q)(1-t_i))k(x-k) > (qt_i - (1-q)(1-t_i))(1-k)(y-k)$$

since $qt_i - (1-q)(1-t_i) > 0$ (by Fact 1), $k > (1-k)$ and $x > k > y$.

If i observes signal β, we have

$$\pi_i(B,\alpha,t_i) > \pi_i(A,\alpha,t_i)$$

as,

$$\begin{aligned} & (1-q)t_ik)x + q(1-t_i)(1-k)y + ((1-q)t_i(1-k) + q(1-t_i)k)k \\ > \; & (q(1-t_i)k)x + (1-q)t_i(1-k)y + ((1-q)t_ik + q(1-t_i)(1-k))k \end{aligned}$$

as,

$$\begin{aligned} & ((1-q)t_ik)(x-k) + q(1-t_i)(1-k)(y-k) \\ > \; & (q(1-t_i)k)(x-k) + (1-q)t_i(1-k)(y-k) \end{aligned}$$

as,

$$((1-q)t_i - q(1-t_i))k(x-k) > ((1-q)t_i - q(1-t_i))(1-k)(y-k)$$

since $(1-q)t_i - q(1-t_i) > 0$ (by Fact 1), $k > (1-k)$ and $x > k > y$.

Collecting the above results we have:

Proposition 1 (Signal revelation). *Under semi-transparency (where only the collective votes are revealed without identifying who voted what and when) there exists an equilibrium where both experts, regardless of their types, vote their signals.*

[Need to add a discussion of the intuition behind signal revelation.]

[Our semi-transparency is more informative than what Levy (2007a) calls secrecy but less informative than Levy's transparency (where individual votes

are revealed). In contrast to Levy, we do not consider any specific voting mechanism (our decision maker is a Bayesian).]

3.3 Impossibility of full revelation under complete transparency

As before, assume that the experts vote their signals. Consider O's beliefs about the experts' types under complete transparency. O gets the same information as D (i.e., the signals), so D's decision can be ignored. The relevant posteriors, given that the experts vote their signals (by hypothesis), are the same for both the experts, irrespective of the timing of their votes:

$$\begin{array}{lll} \Pr(t=\lambda \mid A,a) = & \Pr(t=\lambda \mid B,b) = & \frac{\theta\lambda}{\theta\lambda+(1-\theta)\xi} \\ \Pr(t=\xi \mid A,a) = & \Pr(t=\xi \mid B,b) = & \frac{(1-\theta)\xi}{\theta\lambda+(1-\theta)\xi} \\ \Pr(t=\lambda \mid A,b) = & \Pr(t=\lambda \mid B,a) = & \frac{\theta(1-\lambda)}{\theta(1-\lambda)+(1-\theta)(1-\xi)} \\ \Pr(t=\xi \mid A,b) = & \Pr(t=\xi \mid B,a) = & \frac{(1-\theta)(1-\xi)}{\theta(1-\lambda)+(1-\theta)(1-\xi)}. \end{array} \tag{18}$$

Note that the only difference between the above beliefs and that in (10) is the absence of separate specifications following two different votes by the experts (as the last two specifications in (10)). Now O can observe who voted what (and when), so the updating is based entirely on how an expert's individual vote compares with the realized state and the assumption that this expert will vote his signal (while the other expert may or may not vote his signal).

Given the beliefs stated above, like in section 3.2, we can assert the existence of a revealing equilibrium if voting their signals is indeed an optimal strategy for all types of experts irrespective of when they vote. As O observes the sequence of moves, we specify the experts' payoffs according to the order of moves.

Consider expert i who moves first. If he observes α and votes A, his payoff is

$$\pi_i(A,\alpha,t_i) = \frac{qt_i}{qt_i+(1-q)(1-t_i)}x + \frac{(1-q)(1-t_i)}{qt_i+(1-q)(1-t_i)}y,$$

where x and y are as defined in section 3.2. If i votes B, his payoff is

$$\pi_i(B,\alpha,t_i) = \frac{(1-q)(1-t_i)}{qt_i+(1-q)(1-t_i)}x + \frac{qt_i}{qt_i+(1-q)(1-t_i)}y.$$

Since $qt_i > (1-q)(1-t_i)$ and $x > y$, we have $\pi_i(A,\alpha,t_i) > \pi_i(B,\alpha,t_i)$.

Next suppose i observes β. If he votes B then his payoff is

$$\pi_i(B,\beta,t_i) = \frac{(1-q)t_i}{(1-q)t_i+q(1-t_i)}x + \frac{q(1-t_i)}{(1-q)t_i+q(1-t_i)}y,$$

whereas if he votes A then his payoff is

$$\pi_i(A, \beta, t_i) = \frac{q(1-t_i)}{(1-q)t_i + q(1-t_i)}x + \frac{(1-q)t_i}{(1-q)t_i + q(1-t_i)}y.$$

As $\frac{t_i}{1-t_i} > \frac{q}{1-q}$, and $x > y$, we have $\pi_i(B, \beta, t_i) > \pi_i(A, \beta, t_i)$. Hence, *it is strictly optimal for i to vote his signal, irrespective of his type, and this is true irrespective of whether j (the second mover) will vote his signal or not.*

Now consider the second expert j. Let $g(\alpha) = a$ and $g(\beta) = b$. If j sees a vote B by i, then he knows that i has observed the signal β. Let j observe signal α. Then

$$\Pr(g(\alpha) \mid \beta, \alpha, t_j) = \frac{qt_j(1-\theta\lambda-(1-\theta)\xi)}{qt_j(1-\theta\lambda-(1-\theta)\xi) + (1-q)(1-t_j)(\theta\lambda+(1-\theta)\xi)}.$$

If j votes A, his payoff is

$$\pi_j(A, \beta, \alpha, t_j) = \Pr(g(\alpha) \mid \beta, \alpha, t_j)x + (1 - \Pr(g(\alpha) \mid \beta, \alpha, t_j))y,$$

where x and y, again, are as defined in section 3.2. If j votes B, his payoff is

$$\pi_j(B, \beta, \alpha, t_j) = (1 - \Pr(g(\alpha) \mid \beta, \alpha, t_j))x + \Pr(g(\alpha) \mid \beta, \alpha, t_j)y.$$

So, signal α will be revealed by j if and only if $\pi_j(A, \beta, \alpha, t_j) \geq \pi_j(B, \beta, \alpha, t_j)$:

$$\begin{aligned} qt_j(1-\theta\lambda-(1-\theta)\xi) &\geq (1-q)(1-t_j)(\theta\lambda+(1-\theta)\xi) \\ \text{i.e.,} \qquad \frac{q}{(1-q)}\frac{t_j}{(1-t_j)} &\geq \frac{(\theta\lambda+(1-\theta)\xi)}{(1-\theta\lambda-(1-\theta)\xi)}. \end{aligned}$$

Since $q \geq \frac{1}{2}$ and $\lambda > \xi$, this condition is always met for type λ. Thus the meaningful (necessary and sufficient) condition is

$$\frac{q}{(1-q)}\frac{\xi}{(1-\xi)} \geq \frac{(\theta\lambda+(1-\theta)\xi)}{(1-\theta\lambda-(1-\theta)\xi)}. \tag{19}$$

If this condition does not hold, then the "low" type who observes signal α will deviate contrary to our truthful voting hypothesis and vote against the status-quo, even when the status quo has a (reasonably) strong bias! This is due to the influence of the first expert's vote.

On the other hand, if the second expert j observes signal β, then

$$\Pr(g(\beta) \mid \beta, \beta, t_j) = \frac{(1-q)t_j(\theta\lambda+(1-\theta)\xi)}{(1-q)t_j(\theta\lambda+(1-\theta)\xi) + q(1-t_j)(1-\theta\lambda-(1-\theta)\xi)}.$$

Going through the same steps as above, we find that revelation of signal requires $\pi_j(B, \beta, \beta, t_j) \geq$

$\pi_j(A, \beta, \beta, t_j)$:

$$\begin{aligned} (1-q)t_j(\theta\lambda + (1-\theta)\xi) &\geq q(1-t_j)(1-\theta\lambda-(1-\theta)\xi) \\ \text{i.e.,} \quad \frac{t_j}{(1-t_j)}\frac{(\theta\lambda+(1-\theta)\xi)}{(1-\theta\lambda-(1-\theta)\xi)} &\geq \frac{q}{(1-q)}. \end{aligned}$$

This restriction is always (strictly) satisfied due to Assumption 1.

Now we consider what happens when the second expert sees a first-period vote of A. Let the second expert observe signal α. Then

$$\Pr(g(\alpha) \mid \alpha, \alpha, t_j) = \frac{qt_j(\theta\lambda + (1-\theta)\xi)}{qt_j(\theta\lambda+(1-\theta)\xi) + (1-q)(1-t_j)(1-\theta\lambda-(1-\theta)\xi)}.$$

Going through the same steps as above, we find that revelation of signal requires $\pi_j(A, \alpha, \alpha, t_j) \geq \pi_j(B, \alpha, \alpha, t_j)$:

$$\begin{aligned} qt_j(\theta\lambda + (1-\theta)\xi) &\geq (1-q)(1-t_j)(1-\theta\lambda-(1-\theta)\xi) \\ \text{i.e.,} \quad \frac{q}{(1-q)}\frac{t_j}{(1-t_j)}\frac{(\theta\lambda+(1-\theta)\xi)}{(1-\theta\lambda-(1-\theta)\xi)} &\geq 1. \end{aligned}$$

This restriction is always (strictly) satisfied due to Assumption 1.

Now let the second expert observe signal β. Then

$$\Pr(g(\beta) \mid, \alpha, \beta, t_j) = \frac{(1-q)t_j(1-\theta\lambda-(1-\theta)\xi)}{(1-q)t_j(1-\theta\lambda-(1-\theta)\xi) + q(1-t_j)(\theta\lambda+(1-\theta)\xi)}.$$

Going through the same steps as before, we find that revelation of signal requires $\pi_j(B, \alpha, \beta, t_j) \geq \pi_j(A, \alpha, \beta, t_j)$:

$$\frac{t_j}{(1-t_j)} \geq \frac{q}{(1-q)}\frac{(\theta\lambda+(1-\theta)\xi)}{(1-\theta\lambda-(1-\theta)\xi)}. \tag{20}$$

This condition will never hold for type ξ as $q \geq \frac{1}{2}$, $\lambda > \xi$ and θ is non-degenerate. The condition may also not hold for λ! We collect our results below.

Proposition 2. *Under complete transparency there does not exist an equilibrium where both experts, regardless of their types, will vote their signals.*

We postpone the discussion of the intuition until after we present the equilibrium (existence) result, to which we turn next.

4 Partial revelation under complete transparency

In this section we analyze the case of complete transparency. Given Proposition 2, one should expect that the expert moving second will not always reveal his signal; the first expert can be expected to reveal his signal.

Suppose, for the second period vote, O believes that the expert's type is λ with probability θ and ξ with probability $1-\theta$. This is irrespective of what vote is cast. Then it is optimal for both types of the second expert to vote A with *any* (uniform) probability η, including η degenerate. This, in turn, justifies O's beliefs. We call such voting ***babbling***. Collecting this observation, along with those following (19) and (20), we establish the following equilibrium characterization result:

Proposition 3 (Transparency of expert deliberations). *Consider complete transparency with the individual votes and their timing observable to outsiders. There exists an equilibrium with the following characteristics:*

- *Both types of the expert, who votes first, reveal the signal observed;*
- *If the first vote cast is B (against status quo) and $\frac{q}{(1-q)}\frac{\xi}{(1-\xi)} \geq \frac{(\theta\lambda+(1-\theta)\xi)}{(1-\theta\lambda-(1-\theta)\xi)}$, then the second expert reveals his signal;*

  if the first vote cast is B and $\frac{q}{(1-q)}\frac{\xi}{(1-\xi)} < \frac{(\theta\lambda+(1-\theta)\xi)}{(1-\theta\lambda-(1-\theta)\xi)}$, then the second expert babbles;
- *If the first vote cast is A (pro-status quo), then the expert voting second babbles.*

Compared to semi-transparency, complete transparency fails to always induce truthful recommendation. This is because of the familiar problem of herding: (i) if a low-type expert moving second, with his identity as the second mover known to the outsider, observes a signal that is different from the first-mover's signal, he becomes apprehensive in case his signal proves wrong and therefore strategically goes along with the first mover's recommendation – a case that we call ***weak herding***; (ii) in fact, if the second mover observes a contrarian signal (i.e., one different from the prior bias) and also sees that the first mover has voted different from his own signal, even a high-type second mover may herd with the first mover – a case that we call ***strong herding***. Either type of herding throws out the truthful recommendation equilibrium, as observed in Proposition 2. The self-fulfilling babbling equilibrium, which is always there, then becomes the only other equilibrium (in a specific subgame). Note that in contrast, under semi-transparency, because the second mover's position is not known to the outsider, he does not need to worry about the skepticism that a second mover is normally subjected to, i.e., that he is perhaps a low-type expert given to the temptation of herding. Being free from such skepticism, even a low-type second mover would rely on his signal being accurate and thus recommend truthfully.

5 Secrecy & information revelation

Under secrecy, we will show that in equilibrium experts may or may not always vote their signals. For equilibrium characterization we need some algebraic results on the parameters.

Define the functions:

$$c(k) = \frac{(1-k)(1+k)q}{k(2-k)(1-q)}, \qquad c^{-1}(k) = \frac{k(2-k)(1-q)}{(1-k)(1+k)q}.$$

It is easy to verify that $c(k)$ is decreasing in k ($c^{-1}(k)$ is increasing in k),

$$c(1) = 0, \ \lim_{k\to 0} c(k) = \infty, \text{ and } \ c^{-1}(0) = 0, \ \lim_{k\to 1} c^{-1}(k) = \infty.$$

Therefore there exists a k^*, $k^* = \frac{-1+(1+m^2-m)^{\frac{1}{2}}}{m-1}$ where $m \equiv \frac{q}{1-q}$, such that

$$c(k^*) = c^{-1}(k^*) = 1.$$

Define $\underline{k}(\xi)$ and $\bar{k}(\xi)$ such that

$$c(\underline{k}(\xi)) = \frac{\xi}{1-\xi}, \qquad c^{-1}(\bar{k}(\xi)) = \frac{\xi}{1-\xi}.$$

Since $\frac{\xi}{1-\xi} > 1$, $c(k)$ is decreasing and $c^{-1}(k)$ is increasing, we have:

$$\underline{k}(\xi) < k^* < \bar{k}(\xi)$$

and,

$$\begin{aligned} \frac{\lambda}{1-\lambda} > \frac{\xi}{1-\xi} \geq c(k) \qquad &\text{for} \quad \underline{k}(\xi) \leq k \leq \bar{k}(\xi), \\ \frac{\lambda}{1-\lambda} > \frac{\xi}{1-\xi} \geq c^{-1}(k) \qquad &\text{for} \quad \underline{k}(\xi) \leq k \leq \bar{k}(\xi). \end{aligned}$$

In fact,

$$\begin{aligned} &\underline{k}(\xi) = \frac{-1+(1+l^2-l)^{\frac{1}{2}}}{l-1}, \qquad \bar{k}(\xi) = \frac{-1+(1+r^2-r)^{\frac{1}{2}}}{r-1}, \\ &\text{where } \ l \equiv \frac{q}{1-q}\frac{\xi}{(1-\xi)}, \qquad r \equiv ?. \end{aligned}$$

To see that $\underline{k}(\xi) < \bar{k}(\xi)$, note that the function $\frac{-1+(1+x^2-x)^{\frac{1}{2}}}{x-1}$ is strictly increasing in x. So $\underline{k}(\xi) < \bar{k}(\xi)$, as $\frac{q}{1-q}\frac{(1-\xi)}{\xi} < \frac{q}{1-q}\frac{\xi}{(1-\xi)}$.

Now, assume that the experts vote their signals. The only information that O will have about the votes is through d. Recall, given that the experts vote their signals, D selects B only if two votes are in favor of B; otherwise D selects A (Lemma 1). That is, the Bayesian decision is essentially a B-*unanimity* rule, as per Levy's (2007a) terminology. (When $q = \frac{1}{2}$, for robustness, we assume that D selects A when votes are split.) Therefore when $d = A$, O knows that one of three pairs of signals, (α, α), (α, β), (β, α), could have resulted. When $d = B$, O knows that (β, β) resulted. O's relevant posteriors are then:[7]

$$
\begin{aligned}
\Pr(t = \lambda \mid A, a) &= \frac{\theta[\lambda + (1-\lambda)(\theta\lambda + (1-\theta)\xi)]}{\theta[\lambda + (1-\lambda)(\theta\lambda + (1-\theta)\xi)] + (1-\theta)[\xi + (1-\xi)(\theta\lambda + (1-\theta)\xi)]} \\
\Pr(t = \lambda \mid A, b) &= \frac{\theta[(1-\lambda) + \lambda(1 - \theta\lambda - (1-\theta)\xi)]}{\theta[(1-\lambda) + \lambda(1 - \theta\lambda - (1-\theta)\xi)] + (1-\theta)[(1-\xi) + \xi(1 - \theta\lambda - (1-\theta)\xi)]} \\
\Pr(t = \lambda \mid B, b) &= \frac{\theta\lambda}{\theta\lambda + (1-\theta)\xi} \\
\Pr(t = \lambda \mid B, a) &= \frac{\theta(1-\lambda)}{\theta(1-\lambda) + (1-\theta)(1-\xi)}.
\end{aligned}
$$

Note that $\Pr(t = \xi \mid A, a) = 1 - \Pr(t = \lambda \mid A, a)$, and likewise for the remaining posteriors.

Define

$$x' = \Pr(t = \lambda \mid A, a)\lambda + (1 - \Pr(t = \lambda \mid A, a))\xi$$

$$y' = \Pr(t = \lambda \mid A, b)\lambda + (1 - \Pr(t = \lambda \mid A, b))\xi$$

$$x'' = \Pr(t = \lambda \mid B, b)\lambda + (1 - \Pr(t = \lambda \mid B, b))\xi$$

$$y'' = \Pr(t = \lambda \mid B, a)\lambda + (1 - \Pr(t = \lambda \mid B, a))\xi.$$

The following two results summarize how the experts are likely to recommend the optimal decision under secrecy:

Proposition 4 (Signal revelation). *Consider secrecy (i.e., only D's decision is revealed but not the collective or individual votes or the vote timing). If θ is such that $\underline{k}(\xi) \le k \le \bar{k}(\xi)$, then there exists an equilibrium where both experts vote their signals. Otherwise, there does not exist such an equilibrium.*

Proposition 5 (Incomplete revelation). *Consider the case of secrecy and θ be such that $k \notin \left[\underline{k}(\xi), \bar{k}(\xi)\right]$. There exists an equilibrium where the first expert, irrespective of his type, votes his signal. Following a vote of A, the second expert, irrespective of type, votes his signal. Following a vote of B the second expert babbles, i.e., chooses a voting strategy that is independent of his type or the signal.*

[7] To alert the reader, here the first conditioning variable is the decision d.

From the proof of Proposition 5 it should become clear that even for the intermediate range of k in Proposition 4, there is a second equilibrium in which the second expert babbles.

[We need to explain why the difference from semi-transparency – i.e., sometimes signal fails to be revealed here whereas there is full revelation under semi-transparency. This explanation will indicate why semi-transparency performs better in our environment and exactly where lies the difference from Levy.]

6 Comparison of payoffs

We start by computing D's equilibrium payoffs under Cases 1, 2 and 3.

In the equilibrium under Case 1, signal realizations (α, α), (α, β) and (β, α) are followed by vote pairs (A, A), (A, B) and (B, A) (we are ignoring the order of voting). All of these lead to $d = A$. Following $d = A$, if the state is a then D receives 1 and if the state is b he receives 0. Signals (β, β) lead to $d = B$ and if the state is b then he receives 1, otherwise 0. So D's (ex-ante expected) payoff is,

$$\pi_D^1 = [\Pr(a, \alpha, \alpha) + \Pr(a, \alpha, \beta) + \Pr(a, \beta, \alpha) + \Pr(b, \beta, \beta)].$$

$\Pr(a, \alpha, \alpha)$ is the sum of all probabilities in row one of Table 1. Likewise $\Pr(a, \alpha, \beta)$, $\Pr(a, \beta, \alpha)$, and $\Pr(b, \beta, \beta)$ are, respectively, the sum of all probabilities in row two of Table 1, in row three of Table 1, and in row four of Table 2.

In the equilibrium under Case 2, when $\frac{q}{(1-q)} \frac{\xi}{(1-\xi)} \geq \frac{(\theta\lambda + (1-\theta)\xi)}{(1-\theta\lambda-(1-\theta)\xi)}$, let the payoff of D be denoted π_D^{31}; otherwise, let it be denoted by π_D^{32}. Using arguments similar to above and referring to the relevant equilibrium, we have

$$\pi_D^{21} = [\Pr(a, \alpha, \alpha) + \Pr(a, \alpha, \beta) + \Pr(a, \beta, \alpha) + \Pr(b, \beta, \beta)],$$

$$\pi_D^{22} = [\Pr(a, \alpha, \alpha) + \Pr(a, \alpha, \beta) + \Pr(b, \beta, \alpha) + \Pr(b, \beta, \beta)].$$

In the equilibrium under Case 3, when $\underline{k}(\xi) \leq k \leq \bar{k}(\xi)$, let the payoff of D be denoted π_D^{31}; otherwise, let it be denoted by π_D^{32}. Using arguments similar to above and referring to the relevant equilibrium, we have

$$\pi_D^{31} = [\Pr(a, \alpha, \alpha) + \Pr(a, \alpha, \beta) + \Pr(a, \beta, \alpha) + \Pr(b, \beta, \beta)],$$

$$\pi_D^{32} = [\Pr(a, \alpha, \alpha) + \Pr(a, \alpha, \beta) + \Pr(b, \beta, \alpha) + \Pr(b, \beta, \beta)].$$

Note that

$$\pi_D^1 = \pi_D^{21} = \pi_D^{31}, \tag{21}$$

$$\pi_D^{22} = \pi_D^{32}. \tag{22}$$

Now, $\pi_D^1 - \pi_D^{22} = \Pr(a, \beta, \alpha) - \Pr(b, \beta, \alpha) = k(1-k)(2q-1)$. So,

$$\pi_D^1 = \pi_D^{21} = \pi_D^{31} \geq \pi_D^{22} = \pi_D^{32} \text{ (with strict inequality when } \quad q > \frac{1}{2}). \tag{23}$$

We have thus our central result on the question of ideal transparency from the decision maker's perspective:

Proposition 6 (Ideal transparency). *D weakly prefers semi-transparency over complete transparency and secrecy. The preference is strict over some parameter values.*

[Compare this result with the result of Levy (2007a), who shows that under an appropriate voting rule secrecy (somewhat parallel to our notion of secrecy) is better than transparency (we don't have an exact analog of Levy's transparency; our 'complete transparency' is Levy's transparency plus who voted when).]

To characterize preference over parameter values, we need some technical results. Before proceeding further, we make the following observations to organize our comparison better. Write the condition $\frac{q}{(1-q)}\frac{\xi}{(1-\xi)} \geq \frac{(\theta\lambda+(1-\theta)\xi)}{(1-\theta\lambda-(1-\theta)\xi)}$ as

$$\frac{\xi}{(1-\xi)} \geq \frac{k}{1-k}\frac{1-q}{q} \equiv e(k). \tag{24}$$

Define $\tilde{k}$ such that

$$\frac{\xi}{(1-\xi)} = \frac{\tilde{k}}{1-\tilde{k}}\frac{1-q}{q}.$$

Note that $e(k)$, like $c^{-1}(k)$, is increasing in k. Also

$$e(k) > c^{-1}(k), \quad \text{as } \frac{2-k}{1+k} < 1.$$

So,

$$\tilde{k} < \bar{k}(\xi).$$

We now provide the following ranking characterization:

Proposition 7. *Let $q > \frac{1}{2}$. If $\widetilde{k} < \underline{k}(\xi)$, then when $k \leq \widetilde{k}$, D is indifferent between semi-transparency and complete transparency which are strictly preferred over secrecy; when $k \in \left(\widetilde{k}, \underline{k}(\xi)\right)$, D strictly prefers semi-transparency over both complete transparency and secrecy (which give him equal payoff); when $k \in \left(\underline{k}(\xi), \bar{k}(\xi)\right)$, D is indifferent between semi-transparency and secrecy which is strictly preferred over complete transparency; when $k > \bar{k}(\xi)$, then D strictly prefers semi-transparency over complete transparency and secrecy which give him equal payoff. If $\widetilde{k} > \underline{k}(\xi)$, then when $k \leq \underline{k}(\xi)$, D is indifferent between semi-transparency and complete transparency which are strictly preferred over secrecy; when $k \in \left(\underline{k}(\xi), \widetilde{k}\right)$, D is indifferent between semi-transparency, complete transparency and secrecy; when $k \in \left(\widetilde{k}, \bar{k}(\xi)\right)$, D is indifferent between semi-transparency and secrecy which are strictly preferred over complete transparency; when $k > \bar{k}(\xi)$, then D strictly prefers semi-transparency over complete transparency and secrecy which give him equal payoff.*

A Appendix

Proof: **(Remainder of the argument that the second expert will vote his signal under semi-transparency)**

In section 3.2, we ruled out what we consider offers the strongest incentives for herding: expert j, having privately observed signal β and a first-period vote of A, votes for A as well.

The other type of herding where expert j, having observed signal α and the vote B by i, votes for alternative B, can also be ruled out as follows.

Expert j knows that $s_i^1 = \beta$ (given our hypothesis that the first expert will vote his signal), so if j votes A then $\pi_j(A, \beta, \alpha, t_j) = \theta\lambda + (1-\theta)\xi$. If he votes B, he receives

$$\begin{aligned}\pi_j(B, \beta, \alpha, t_j) &= \Pr(b \mid \beta, \alpha, t_j)\left[\frac{\theta\lambda}{k}\lambda + \frac{(1-\theta)\xi}{k}\xi\right] + \Pr(a \mid \beta, \alpha, t_j)\left[\frac{\theta(1-\lambda)}{1-k}\lambda + \frac{(1-\theta)(1-\xi)}{1-k}\xi\right] \\ &= \frac{(1-q)(1-t_j)k}{(1-q)(1-t_j)k + qt_j(1-k)}\left[\frac{\theta\lambda}{k}\lambda + \frac{(1-\theta)\xi}{k}\xi\right] \\ &\quad + \frac{qt_j(1-k)}{(1-q)(1-t_j)k + qt_j(1-k)}\left[\frac{\theta(1-\lambda)}{1-k}\lambda + \frac{(1-\theta)(1-\xi)}{1-k}\xi\right].\end{aligned}$$

Compared against (16), observe that

$$\begin{array}{rrl} & & \pi_j(B,\beta,\alpha,t_j) < \pi_j(A,\alpha,\beta,t_j), \\ & \text{if} & \Pr(b \mid \beta,\alpha,t_j) < \Pr(a \mid \alpha,\beta,t_j) \\ \text{i.e.,} & \text{if} & \dfrac{(1-q)(1-t_j)k}{(1-q)(1-t_j)k + qt_j(1-k)} < \dfrac{q(1-t_j)k}{q(1-t_j)k + (1-q)t_j(1-k)} \\ \text{i.e.,} & \text{if} & (1-q)^2 < q^2 \\ \text{i.e.,} & \text{if} & q > \dfrac{1}{2}, \end{array}$$

which is true by assumption. Further, it was shown that $\pi_j(A,\alpha,\beta,t_j) < \theta\lambda + (1-\theta)\xi$, so

$$\pi_j(B,\beta,\alpha,t_j) < \theta\lambda + (1-\theta)\xi = \pi_j(A,\beta,\alpha,t_j).$$

Thus, once again the second expert will not herd and instead vote his signal.

Let us next consider the scenario that the second expert observes signal β and sees a first-period vote B. He knows that $s_i^1 = \beta$. So if j votes A then $\pi_j(A,\beta,\beta,t_j) = \theta\lambda + (1-\theta)\xi$. If he votes B, he receives

$$\begin{aligned} & \pi_j(B,\beta,\beta,t_j) \\ = \; & \Pr(b \mid \beta,\beta,t_j)\left[\frac{\theta\lambda}{k}\lambda + \frac{(1-\theta)\xi}{k}\xi\right] + \Pr(a \mid \beta,\beta,t_j)\left[\frac{\theta(1-\lambda)}{1-k}\lambda + \frac{(1-\theta)(1-\xi)}{1-k}\xi\right] \qquad \text{(A.1)} \\ = \; & \frac{(1-q)t_jk}{(1-q)t_jk + q(1-t_j)(1-k)}\left[\frac{\theta\lambda}{k}\lambda + \frac{(1-\theta)\xi}{k}\xi\right] \\ & + \frac{q(1-t_j)(1-k)}{(1-q)t_jk + q(1-t_j)(1-k)}\left[\frac{\theta(1-\lambda)}{1-k}\lambda + \frac{(1-\theta)(1-\xi)}{1-k}\xi\right]. \end{aligned}$$

Therefore,

$$\begin{array}{rrl} & & \pi_j(B,\beta,\beta,t_j) > \pi_j(A,\beta,\beta,t_j), \\ & \text{if} & \dfrac{(1-q)t_j\theta\lambda}{(1-q)t_jk + q(1-t_j)(1-k)}\lambda + \dfrac{q(1-t_j)\theta(1-\lambda)}{(1-q)t_jk + q(1-t_j)(1-k)}\lambda > \theta\lambda \\ \text{i.e.,} & \text{if} & \dfrac{(1-q)t_j\lambda + q(1-t_j)(1-\lambda)}{(1-q)t_jk + q(1-t_j)(1-k)} > 1 \\ \text{i.e.,} & \text{if} & (1-q)t_j(\lambda-k) > q(1-t_j)(\lambda-k) \\ \text{i.e.,} & \text{if} & \dfrac{t_j}{1-t_j} > \dfrac{q}{1-q}, \end{array}$$

which is true due to Fact 1. So j will vote his signal.

Finally, suppose j has observed signal α and a first-period vote A. He knows that $s_i^1 = \alpha$. So j's expected payoff from voting B is $\pi_j(B,\alpha,\alpha,t_j) = \theta\lambda + (1-\theta)\xi$, whereas by voting A (his signal) he receives

$$\pi_j(A,\alpha,\alpha,t_j) = \Pr(a \mid \alpha,\alpha,t_j)\left[\frac{\theta\lambda}{k}\lambda + \frac{(1-\theta)\xi}{k}\xi\right] + \Pr(b \mid \alpha,\alpha,t_j)\left[\frac{\theta(1-\lambda)}{1-k}\lambda + \frac{(1-\theta)(1-\xi)}{1-k}\xi\right]. \tag{A.2}$$

Comparing (A.1) and (A.2), and given that $\pi_j(B,\beta,\beta,t_j) > \pi_j(A,\beta,\beta,t_j)$ (as established above) and $\pi_j(B,\alpha,\alpha,t_j) = \pi_j(A,\beta,\beta,t_j)$, we can conclude that

$$\begin{aligned}
& \pi_j(A,\alpha,\alpha,t_j) > \pi_j(B,\alpha,\alpha,t_j), \\
\text{if} \quad & \Pr(a \mid \alpha,\alpha,t_j) > \Pr(b,\beta,\beta,t_j) \\
\text{i.e., if} \quad & \frac{qt_jk}{qt_jk + (1-q)(1-t_j)(1-k)} > \frac{(1-q)t_jk}{(1-q)t_jk + q(1-t_j)(1-k)} \\
\text{i.e., if} \quad & q^2 > (1-q)^2 \quad \text{(after simplifying)} \\
\text{i.e., if} \quad & q > \frac{1}{2},
\end{aligned}$$

which is true by assumption. Thus, when the second expert sees a first-period vote A and his own signal is α, he votes his signal.

This completes our argument that j will always vote his signal, assuming that i has voted his signal. $\quad ||$

Proof Proposition 4. Suppose experts vote their signals. Let the first expert i observe signal α. If he votes A then irrespective of what the second expert votes, $d = A$. So the expert receives a payoff:

$$\pi_i(A,\alpha_i,t_i) = \frac{qt_ik}{H(t_i)}x' + \frac{(1-q)(1-t_i)(1-k)}{H(t_i)}y' + \frac{qt_i(1-k)}{H(t_i)}x' + \frac{(1-q)(1-t_i)k}{H(t_i)}y'.$$

If he votes B then d depends on whether j observes α or β. This payoff can be written as:

$$\pi_i(B,\alpha_i,t_i) = \frac{qt_ik}{H(t_i)}x' + \frac{(1-q)(1-t_i)(1-k)}{H(t_i)}y' + \frac{qt_i(1-k)}{H(t_i)}y'' + \frac{(1-q)(1-t_i)k}{H(t_i)}x''.$$

Substituting terms and with some algebra we obtain:

$$\begin{aligned}
& \pi_i(A,\alpha_i,t_i) \geq \pi_i(B,\alpha_i,t_i) \\
\Leftrightarrow \quad & \frac{q}{(1-q)}\frac{t_i}{1-t_i}\left[\Pr(\lambda \mid A,a) - \Pr(\lambda \mid B,a)\right] \geq \frac{k}{1-k}\left[\Pr(\lambda \mid B,b) - \Pr(\lambda \mid A,b)\right] \\
\Leftrightarrow \quad & \frac{t_i}{1-t_i} \geq c^{-1}(k).
\end{aligned}$$

Let i observe signal β. Then,

$$\begin{aligned}
&\pi_i(B, \beta_i, t_i) \geq \pi_i(A, \beta_i, t_i) \\
\Leftrightarrow\quad &\frac{t_i}{1-t_i}\frac{k}{1-k}\left[\Pr(\lambda \mid B, b) - \Pr(\lambda \mid A, b)\right] \geq \frac{q}{(1-q)}\left[\Pr(\lambda \mid A, a) - \Pr(\lambda \mid B, a)\right] \\
\Leftrightarrow\quad &\frac{t_i}{1-t_i} \geq c(k).
\end{aligned}$$

But $\frac{t_i}{1-t_i} \geq c^{-1}(k)$ and $\frac{t_i}{1-t_i} \geq c(k)$ if and only if $\underline{k}(\xi) \leq k \leq \bar{k}(\xi)$.

Now consider the second expert j. If he sees a first-period vote of A then he knows that $d = A$, so he is indifferent between voting A and voting B. Thus, it is optimal for j to vote his signal.

Suppose j sees vote B. He knows that i voted his signal, so $s_i = \beta$. Let j observe signal α. Then,

$$\begin{aligned}
&\pi_i(A, \beta_i, \alpha_j, t_j) \geq \pi_i(B, \beta_i, \alpha_j, t_j) \\
\Leftrightarrow\quad &\frac{q}{(1-q)}\frac{t_j}{1-t_j}\left[\Pr(\lambda \mid A, a) - \Pr(\lambda \mid B, a)\right] \geq \frac{k}{1-k}\left[\Pr(\lambda \mid B, b) - \Pr(\lambda \mid A, b)\right] \\
\Leftrightarrow\quad &\frac{t_j}{1-t_j} \geq c^{-1}(k).
\end{aligned}$$

Let j observe signal β. Then,

$$\begin{aligned}
&\pi_i(B, \beta_i, \beta_j, t_j) \geq \pi_i(A, \beta_i, \beta_j, t_j) \\
\Leftrightarrow\quad &\frac{t_j}{1-t_j}\frac{k}{1-k}\left[\Pr(\lambda \mid B, b) - \Pr(\lambda \mid A, b)\right] \geq \frac{q}{(1-q)}\left[\Pr(\lambda \mid A, a) - \Pr(\lambda \mid B, a)\right] \\
\Leftrightarrow\quad &\frac{t_j}{1-t_j} \geq c(k).
\end{aligned}$$

But then again, $\frac{t_j}{1-t_j} \geq c^{-1}(k)$ and $\frac{t_j}{1-t_j} \geq c(k)$ if and only if $\underline{k}(\xi) \leq k \leq \bar{k}(\xi)$. ■

Proof of Proposition 5. To calculate equilibrium beliefs about the experts' types, suppose the experts follow their respective strategies as specified (the optimality of strategies to be verified later). Then, for vote pairs (A, A) and (A, B), the decision maker will choose $d = A$ (Lemma 1). If the first expert votes B (i.e. for vote pairs (B, A) and (B, B)), the decision maker will select $d = B$ based only on the first expert's vote; the second vote is uninformative. Hence for O the beliefs are as follows (note that they are the same as in (18)):

$$\begin{aligned}
\Pr(t = \lambda \mid A, a) = \quad \Pr(t = \lambda \mid B, b) &= \quad \tfrac{\theta\lambda}{\theta\lambda + (1-\theta)\xi} \\
\Pr(t = \xi \mid A, a) = \quad \Pr(t = \xi \mid B, b) &= \quad \tfrac{(1-\theta)\xi}{\theta\lambda + (1-\theta)\xi} \\
\Pr(t = \lambda \mid A, b) = \quad \Pr(t = \lambda \mid B, a) &= \quad \tfrac{\theta(1-\lambda)}{\theta(1-\lambda) + (1-\theta)(1-\xi)} \\
\Pr(t = \xi \mid A, b) = \quad \Pr(t = \xi \mid B, a) &= \quad \tfrac{(1-\theta)(1-\xi)}{\theta(1-\lambda) + (1-\theta)(1-\xi)}.
\end{aligned}$$

The beliefs are applicable to both experts, given that neither the experts' identities nor the timing of moves are revealed.

Recall, from section 3.2, that

$$x \equiv \frac{\theta\lambda}{\theta\lambda + (1-\theta)\xi}\lambda + \frac{(1-\theta)\xi}{\theta\lambda + (1-\theta)\xi}\xi \,,$$

$$y \equiv \frac{\theta(1-\lambda)}{\theta(1-\lambda) + (1-\theta)(1-\xi)}\lambda + \frac{(1-\theta)(1-\xi)}{\theta(1-\lambda) + (1-\theta)(1-\xi)}\xi \,.$$

Now consider expert i who moves first. Let him observe α. If he votes A, he receives

$$\pi_i(A, \alpha, t_i) = \frac{qt_i}{qt_i + (1-q)(1-t_i)}x + \frac{(1-q)(1-t_i)}{qt_i + (1-q)(1-t_i)}y.$$

If he votes B, his payoff is

$$\pi_i(B, \alpha, t_i) = \frac{(1-q)(1-t_i)}{qt_i + (1-q)(1-t_i)}x + \frac{qt_i}{qt_i + (1-q)(1-t_i)}y.$$

Since $qt_i > (1-q)(1-t_i)$ and $x > y$, we have $\pi_i(A, \alpha, t_i) > \pi_i(B, \alpha, t_i)$. Now suppose he observes β. If he votes B, his payoff is

$$\pi_i(B, \beta, t_i) = \frac{(1-q)t_i}{(1-q)t_i + q(1-t_i)}x + \frac{q(1-t_i)}{(1-q)t_i + q(1-t_i)}y.$$

If he votes A, he receives

$$\pi_i(A, \beta, t_i) = \frac{q(1-t_i)}{(1-q)t_i + q(1-t_i)}x + \frac{(1-q)t_i}{(1-q)t_i + q(1-t_i)}y.$$

As $\frac{t_i}{1-t_i} > \frac{q}{1-q}$, and $x > y$, we have $\pi_i(B, \beta, t_i) > \pi_i(A, \beta, t_i)$. Hence, it is strictly optimal for i to vote his signal, irrespective of his type. Now, given a first-period vote of A, the second expert j knows that $d = A$. His payoff remains unchanged whether he votes A or B. So j voting his signal is optimal. Similarly, if the first vote is B, j's vote is immaterial and $d = B$. Hence again, j's payoff remains unchanged whether he votes A or B. So it is optimal for j to babble. ■

Proof of Proposition 7. Let $\tilde{k} < \underline{k}(\xi)$. Suppose $k \leq \tilde{k}$, then $\frac{\xi}{(1-\xi)} \geq e(k)$, but $\frac{\xi}{(1-\xi)} < c(k)$. So, the equilibrium payoffs of D are π_D^1, π_D^{21} and π_D^{32}. And we have $\pi_D^1 = \pi_D^{21} > \pi_D^{32}$, which is what the Proposition states. Let $k \in \left(\tilde{k}, \underline{k}(\xi)\right)$, then $\frac{\xi}{(1-\xi)} < e(k)$, and $\frac{\xi}{(1-\xi)} < c(k)$. So, the equilibrium payoffs of D are π_D^1, π_D^{22} and π_D^{32}. And we have $\pi_D^1 > \pi_D^{22} = \pi_D^{32}$, which is what the Proposition states. When $k \in \left(\underline{k}(\xi), \bar{k}(\xi)\right)$, we have $\frac{\xi}{(1-\xi)} < e(k)$, but $\frac{\xi}{(1-\xi)} > c^{-1}(k)$ and $\frac{\xi}{(1-\xi)} > c(k)$. So, the equilibrium payoffs of D are π_D^1, π_D^{22} and π_D^{31}. And we have $\pi_D^1 = \pi_D^{32} > \pi_D^{22}$ and the Proposition holds true. When $k > \bar{k}(\xi)$, we have

$\frac{\xi}{(1-\xi)} < e(k)$ and $\frac{\xi}{(1-\xi)} < c^{-1}(k)$. So, the equilibrium payoffs of D are π_D^1, π_D^{22} and π_D^{32}. We then have $\pi_D^1 > \pi_D^{22} = \pi_D^{32}$ as claimed in the Proposition. Similar arguments can be used to verify the Proposition when $\tilde{k} > \underline{k}(\xi)$. ■

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