Delegating Decisions to Experts

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July 28, 2001

ABSTRACT. A model of delegation and expertise is presented, with self-interested and privately-informed decisionmakers and experts. Conflict of interests exists both between the decisionmakers and the experts, and between experts within a team. A balanced team of experts with extreme and opposite biases is shown to be acceptable to a wide range of decisionmakers with diverse preferences, but the value of expertise from such a team is low. We also find that a decisionmaker wants to appoint experts who are less partisan than himself, in order to facilitate the pooling of information and thereby increase the quality of decisions by the expert team. Selective delegation, either by controlling the decisionmaking process or by conditioning the delegation decision on his own information, is another effective way for the decisionmaker to safeguard own interests while making use of expert information.

* This paper is dedicated to the memory of Sherwin Rosen. It grew out of discussions with him in writing a companion paper, Li, Rosen and Suen (forthcoming), and would not have been possible without his insights and encouragement. We also received valuable comments from Doug Allen, William Chan, Julian Jamison, Edward Lazear, Steve Tadelis, and Keith Wong.

A good executive is the one who understands how to recruit people and how to delegate.

George W. Bush

1. Introduction

Individuals cannot be expected to be well informed about all the decisions they have to make. Increasing returns to the use of knowledge imply that it pays for different individuals to specialize in different problems (Garicano, 2000). When a person is confronted with a problem beyond his specialty, he can make the decision by himself based on his limited information, or he can seek the help of better-informed experts. Offering advice is cheap for an expert who already possesses the relevant information, so the usual agency problem associated with costly effort may not be a major concern. Nevertheless, an expert who is offering advice may have a stake himself in the decision. His advice may be influenced by preferences that do not accord with those of the decisionmaker who is seeking his advice. Our paper studies agency problems of this kind.

Consider, for example, a corporate chief executive officer who has to make a decision on whether to adopt a certain investment project. The marketing division head has better information about the profitability of the project than does the CEO, but he is also more biased toward adoption because he is interested in expanding his own division. Will the CEO delegate the decision to the marketing division head? It turns out that the answer depends on the CEO's default choice if he is to make the decision himself. Suppose the CEO is predisposed to adopt the investment project based on his own prior. Delegating the decision to the marketing division head will change the outcome when the latter recommends rejection. Since he is biased toward adoption, the marketing division head recommends rejection only when receiving strong negative signals about the profitability of the project. Therefore the CEO cannot lose by delegating the decision to the market division head, and often gains from the latter's expert information. Suppose, alternatively, that the CEO will reject the investment project based on his own prior. In this case, delegation will make a difference when the marketing division head chooses to adopt the project. If he is sufficiently biased toward expanding his own division, the marketing division head will adopt the project based on relatively weak signals about profitability. If following such a recommendation is not to the benefit of the corporation, delegation will not occur.

Such agency problems in decisionmaker-expert relationships can arise even when narrow self interests are not an issue. For example, an expert on public policy may offer advice based on noble convictions. But as long as his convictions are not identical to those of the policy decisionmaker, there will be conflict of interests between the two parties and the decisionmaker has to devise ways to reduce manipulation by his better-informed advisor.

In this paper we discuss delegation mechanisms that can be used by decisionmakers to mitigate the agency problem of information manipulation in non-market organizations. In the kind of decisionmaker-expert relationship that we study, the decisionmaker and the experts do not interact through monetary payment for recommendation on a case-by-case basis, as might occur when the CEO of a corporation deals with an external management consultant. Instead, the decisionmaker has to choose between dictating the decision without consulting the expert and delegating the decision to the expert. If a decisionmaker faces no restriction in selecting the expert, the agency problem that arises from conflicts of interests in delegation is solved by having an expert who shares the same preferences. But in practice, the effectiveness of such a solution is limited. Scale economies in the investment in expertise imply that there may be only a limited number of experts to select from. In non-market organizations, experts are often recruited before their private information is gathered, and to ensure a wide use of their expertise, experts are often employed to help out multiple decisionmakers or the same decisionmaker on different decisions. For example, a cabinet member is selected to advise the president on many decisions, and the biases of the member and the president can shift according to each individual decision.

Delegation does not occur if the preferences of an uninformed decisionmaker and an informed expert are too far apart. We show that an expert with more extreme preferences has a greater chance of being delegated with the decision by decisionmakers with similar but less extreme preferences. For example, when a Republican president picks an extreme conservative cabinet member he can safely delegate more decisions and make use of the member's expertise. Unfortunately, there is a trade-off between the use and the benefit of expertise: an expert with more extreme preferences is more likely to be delegated with different decisions, but his expertise is less useful to the decisionmaker on a given decision. To continue the above example, a strongly conservative cabinet member can be relied upon to safeguard the interests of the Republican president, but precisely due to his strong bias, on most decisions the member will make the same choices as the uninformed president would, which reduces the value of his expertise to the president.

A key to reducing manipulation is to recruit the right expert. Obviously the ideal expert on a given decision is one with identical preferences as the decisionmaker's. However, if the decisionmaker is to appoint a delegate to sit on a committee of experts that will make the decision, the best choice is not to appoint a clone. For example, suppose committee members are prone to raise taxes while the decisionmaker is a tax-cutting Republican. If he picks an equally staunch Republican as his delegate, the committee will be beset by great conflicts and expert information will be poorly utilized. The decisionmaker can do better by appointing someone whose preferences are somewhere between his own and the other committee members' preferences. Although this delegate will not vote exactly the way the decisionmaker would, there will be less manipulation and the quality of the committee decision will be higher, benefiting the decisionmaker.

An informed decisionmaker can condition the delegation decision on his own private signals. He delegates the decision to the expert when his own evidence is not indicative of which decision should be made, and retains control over the decision when his evidence is strong. Consider again the example of the CEO and the marketing division head. Since the latter is prone to adopt the investment project, the CEO may be tempted to reject the project on his own and delegate the decision only when his own information provides insufficient evidence against adoption of the project. An even better delegation mechanism for the CEO is to retain control of both adoption and rejection decisions and delegate when his own information is inconclusive either for or against adoption.

Such selective use of delegation reduces manipulation by the marketing division head and increases the value of his expertise.

We illustrate these issues of delegation and expertise using a model, set up in section 2, in which the decision to be made and the underlying state of the world are both binary, but the data of the experts are continuously distributed. Such data are imperfect signals of the true state. How they are used in the decisionmaking process depends on the agents' preferences, which are represented by their prior and their costs of type I and type II errors. In section 3 we first consider the case of an uninformed decisionmaker and a single expert. In this case, delegation and incentive compatibility are equivalent: an uninformed decisionmaker is willing to delegate to an expert if and only if the decisionmaker has the incentive to follow an expert's recommendation.[1] We then consider in section 4 the case of an uninformed decisionmaker and a team of two privately-informed and self-interested experts. We assume that in delegating decisions to a team of experts, the decisionmaker can control the decisionmaking procedure of the team. The model of strategic information aggregation in the expert team that we use follows Li, Rosen and Suen (forthcoming). In section 5 we extend the discussion to the case of an informed decisionmaker and an informed expert. We discuss selective use of delegation based on the decisionmaker's private information. The analysis turns out be similar to the case of a team of two experts. The last section concludes the paper with a brief review of the related literature, and some suggestions for further research in the present framework.

2. A Binary Decision Model of Expertise

The framework of our model is borrowed from optimal statistical decisions (DeGroot, 1970). To facilitate the exposition, we adopt the language of policy evaluation. A policy change under consideration has either positive or negative net benefit. The decision to be made is either to "adopt" or "reject" the policy change. For convenience, we will think of rejection of the policy change as the status quo choice. With some name changes,

[1] Because of the binary nature of the decision, the expert cannot convey more than a "yes" or "no" recommendation even though their private information is continuously distributed. This result is a special case of Crawford and Sobel's (1982) model of strategic information transmission.

our model describes a variety of decisionmaker-expert situations, such as a CEO and a marketing division head about an investment project, an editor and a referee about a journal article, a department chair and a hiring committee about a job candidate, and so on.

There are two types of agents who may be involved in the decisionmaking: decisionmaker D, who has the formal authority of making the decision, and experts A and B, who may be delegated by D to make the decision. We use superscript d to represent the notation for the decisionmaker, and superscripts a and b to represent the notation for experts A and B, respectively. We specify the preferences of any agent $i = d, a, b$ as follows. Let γ^i be the prior of the agent that the policy change has positive net benefit. Denote as λ_1^i the utility cost of type I error (false adoption) and λ_2^i the utility cost of type II error (false rejection).[2] Each agent wishes to minimize expected cost. Write $k_1^i = \lambda_1^i(1 - \gamma^i)$ and $k_2^i = \lambda_2^i \gamma^i$. The ratio $k^i = k_1^i / k_2^i$ represents the expected cost of false adoption relative to false rejection under the prior, and completely characterizes the preferences of the agent.[3] A greater k^i means that the agent is more prone to rejection. We say that agent i has "neutral" preferences if $k^i = 1$. If $k^i < 1$, we call agent i a "liberal." If $k^i > 1$, we call him a "conservative." A liberal will adopt the policy change based his prior beliefs and preferences, while a conservative will reject the policy change. Throughout the paper, we assume that preferences of all agents are common knowledge.

Information structure is modeled as follows. Each agent $i = d, a, b$, if informed, privately observes a one-dimensional signal y^i. The signal y^i is assumed to be distributed on $[\underline{y}^i, \overline{y}^i]$ (the bounds can be infinity), with differentiable density function f_p^i and corresponding distribution function F_p^i conditional on the state that the policy change has positive net benefit, and with f_n^i and F_n^i conditional on the state that the policy change has negative benefit.[4] For simplicity, when multiple informed agents are involved, we

[2] The cost of making the correct decision (i.e., adopt when the policy change has positive benefit, and reject when the policy has negative benefit) is normalized to zero.

[3] There is no difference in this model between bias as manifested in γ^i and preferences as manifested in λ_1^i and λ_2^i; only the ratio k^i matters. We use the words "bias" and "preferences" interchangeably.

[4] In the related literature on strategic voting (Feddersen and Pesendorfer, 1996, 1997), the signals

assume that the signals are independent conditional on the true state.

We introduce some notation that will be used throughout the paper. For any signal y^i, let $l^i(y^i)$ denote the likelihood ratio $f_p^i(y^i)/f_n^i(y^i)$. Write $L_*^i(y^i) = F_p^i(y^i)/F_n^i(y^i)$, and $L_{**}^i(y^i) = [1 - F_p^i(y^i)]/[1 - F_n^i(y^i)]$. For any $y_2^i > y_1^i$, denote as $\mathcal{L}^i(y_2^i, y_1^i)$ the ratio $[F_p^i(y_2^i) - F_p^i(y_1^i)]/[F^i(y_2^i) - F_n^i(y_1^i)]$. We assume that the monotone likelihood ratio property holds, that is, $l^i(y^i)$ is strictly increasing (Milgrom, 1981). A higher observed value of y^i is stronger evidence that the policy change has positive net benefit. It is easy to verify that strict monotone likelihood ratio property implies the following

Facts.

1. $L_*^i(y^i) < 1 < L_{**}^i(y^i)$ for any $y^i \in (\underline{y}^i, \overline{y}^i)$;
2. $L_*^i(y^i) < l(y^i) < L_{**}^i(y^i)$ for any $y^i \in (\underline{y}^i, \overline{y}^i)$;
3. $L_*^i(y^i)$ and $L_{**}^i(y^i)$ are both strictly increasing functions;
4. $\mathcal{L}^i(y_2^i, y_1^i)$ is strictly increasing in both arguments for all $y_2^i > y_1^i$.

Lastly, for the analysis with multiple informed agents, we also assume that l^i/L_*^i and l^i/L_{**}^i are increasing functions in order to carry out comparative statics exercises. These assumptions are satisfied by, for example, normal distributions with a shift in mean to represent the true state.

Decisionmaker D may decide to dictate the decision based on his own prior or information, without consulting any expert. Alternatively, D may decide to delegate the decision to an expert or a team of experts. We assume that in delegating the decision, the decisionmaker can commit to not overruling the decision by the experts.[5] The choice between dictating the decision and delegating it may seem to be an artificial

as well as the states are binary. Here we follow Crawford and Sobel (1982) in assuming continuously distributed signals. This allows us to study strategic information transmission and aggregation in terms of thresholds strategies, which are more intuitive and less cumbersome than mixed strategies in models of binary signals.

[5] This assumption is made to facilitate the presentation. We will see below that commitment is not needed in the case of delegating decision to a single expert, either by an uninformed decisionmaker or an informed one, because the willingness to delegate is itself a credible commitment to not overruling the expert. In the case of delegating to a team of experts, the commitment to not overruling the team's decision has value only when the decisionmaker monitors how the team makes the decision after delegation.

one, in the sense that in reality decisionmakers often have other means of eliciting the expert information, such as asking the experts for a recommendation and promising to act on it in a particular way. However, as a decentralized way of resolving the conflicts between the decisionmaker and the experts and making use of the expertise, delegation has a simple administrative structure that makes it easy to implement. Further, for the decisionmaker, delegation is a convincing commitment to allowing the experts to have their say. As we will see below, in some contexts, the decisionmaker cannot do better than simply delegating the decision to the experts.[6]

3. Delegating Decisions to a Single Expert

In this section, we assume that decisionmaker D is uninformed. When making an uninformed decision, D will choose adoption if the cost of false adoption is less than the cost of false rejection, and rejection otherwise. Thus, a liberal decisionmaker will choose adoption and a conservative decisionmaker will choose rejection.

If decisionmaker D delegates the decision to expert A, the expert will make the decision based on the observed value of y^a. The expert uses Bayes' rule to update the posterior probabilities of the policy change having positive and negative net benefit to $\eta\gamma^a f_p^a(y^a)$ and $\eta(1-\gamma^a)f_n^a(y^a)$, respectively, where η is a normalizing factor to make the probabilities sum to one. Expert A will adopt if $\eta(1-\gamma^a)f_n^a(y^a)\lambda_1^a \leq \eta\gamma^a f_p^a(y^a)\lambda_2^a$. This condition reduces to the rule that A will choose adoption if $y^a \geq \hat{t}^a$, and choose rejection otherwise, where $\hat{t}^a$ is defined by $l^a(\hat{t}^a) = k^a$ (DeGroot, 1970).

According to expert A's optimal decision rule, the expected cost C^d to decisionmaker D is

$$C^d = k_1^d(1 - F_n^a(\hat{t}^a)) + k_2^d F_p^a(\hat{t}^a). \tag{1}$$

Thus, if the decisionmaker is a liberal, he prefers delegating the decision to expert A to making an uninformed adoption decision if and only if $k_1^d \geq C^d$. This is equivalent to the requirement that $k^d \geq L_*^a(\hat{t}^a)$. Similarly, if the decisionmaker is a conservative, he

[6] Another rationale for delegation is given by Aghion and Tirole (1997), who argue that delegation by a decisionmaker gives the expert greater incentives to acquire relevant information. In our paper, the information structure is taken as given, but we also discuss the quality of expertise. Such a discussion can be extended to consider information acquisition.

prefers delegating the decision to expert A to making an uninformed rejection decision if and only if $k_2^d \geq C^d$, which is equivalent to $k^d \leq L_{**}^a(\hat{t}^a)$. Define $\theta_1^a = L_*^a(\hat{t}^a)$ and $\theta_2^a = L_{**}^a(\hat{t}^a)$. Note that $\theta_1^a < 1 < \theta_2^a$ (Fact 1). We summarize the above results in the following proposition:

PROPOSITION 1. *There exist two critical values $\theta_1^a < \theta_2^a$, such that decisionmaker D dictates adoption he is sufficiently liberal ($k^d < \theta_1^a$), dictates rejection if he is sufficiently conservative ($k^d > \theta_2^a$), and delegates the decision to expert A if k^d is in between these critical values.*

In our discussion, we have assumed that the decisionmaker can commit to not overruling the expert after the latter has made the decision. It turns out that this commitment is indeed credible if k^d is between θ_1^a and θ_2^a. To see this, suppose expert A has made a decision to adopt. The decisionmaker infers that $y^a \geq \hat{t}^a$. Decisionmaker D therefore updates his posterior probabilities of the policy change having positive and negative net benefit to $\eta\gamma^d(1 - F_p^a(\hat{t}^a))$ and $\eta(1-\gamma^d)(1 - F_n^a(\hat{t}^a))$, respectively (where η is a normalizing factor to make the probabilities sum to one.) Based on these updated probabilities, the decisionmaker would choose adoption over rejection if $k^d \leq \theta_2^a$, implying that it would not be optimal to overrule the expert's adoption decision. Similar reasoning suggests that D has no incentive to overrule A's rejection decision since $k^d \geq \theta_1^a$. Thus, provided that the decisionmaker finds that delegating the decision to the expert is better than making the decision by himself, he has no incentive to overrule the expert subsequent to learning the expert's decision.

More generally we can show that the decisionmaker cannot do better than delegation by committing to any mechanism to elicit the information from the experts.[7] In keeping with our intent to address issues of managing expertise in organizations, we assume that monetary transfers are not used in such mechanisms. The proof of the following result is in the appendix.

[7] This result depends on our assumption that the decisionmaker makes a binary choice. In a more general setup, delegation can be dominated for the decisionmaker by a "communication" mechanism, where the decisionmaker asks for a recommendation from the expert and responds to it optimally. See Dessein (2001).

PROPOSITION 2. *In any incentive compatible mechanism, the probability of adoption* $p(y^a)$ *takes only two values* $p_1 \geq p_0$, *such that* $p(y^a) = p_1$ *for all* $y^a \geq \hat{t}^a$, *and* $p(y^a) = p_0$ *otherwise. Furthermore, the optimal mechanism for the decisionmaker satisfies* $p_0 = p_1 = 1$ *(i.e., always adopt) if* $k^d < \theta_1^a$; $p_0 = p_1 = 0$ *(i.e., always reject) if* $k^d > \theta_2^a$; *and* $p_0 = 0$ *and* $p_1 = 1$ *if* k^d *is between* θ_1^a *and* θ_2^a.

The coarsening of information in incentive schemes is a generic feature of strategic information transmission (Crawford and Sobel, 1982). The first part of Proposition 2 states that information of the expert will be coarsened into at most a two-way partition in equilibrium. This results from the binary nature of the decision. The second part of Proposition 2 shows that, in an optimal mechanism, the decisionmaker will always adopt if $k^d < \theta_1^a$ and he will always reject if $k^d > \theta_2^a$. This is equivalent to letting the decisionmaker make an uninformed decision since $k^d < \theta_1^a$ implies $k^d < 1$ while $k^d > \theta_2^a$ implies $k^d > 1$ (Fact 1). When the value of k^d lies between θ_1^a and θ_2^a, the best that an incentive compatible mechanism can achieve is to choose adoption if $y^a \geq \hat{t}^a$ and rejection if $y^a < \hat{t}^a$. This is equivalent to delegating the decision to the expert. Thus delegating to the expert corresponds to the best possible mechanism. In case of delegating to a single expert, the equivalence of delegation mechanisms (where the expert is given the authority to make the decision for the decisionmaker) and incentive mechanisms (where the decisionmaker commits to a rule that specifies how he responds to the recommendation of the expert) holds in more general models of delegation such as Holmstrom (1984). Whether it holds when there are multiple experts who are privately informed (Section 4) or when the decisionmaker himself has private information (Section 5), depends on what is allowed by incentive mechanisms and delegation mechanisms. In the present paper, we are interested in delegation mechanisms that involve some degree of control and are natural because of their simplicity of implementation and their credibility in precommitment.

A. Advocacy

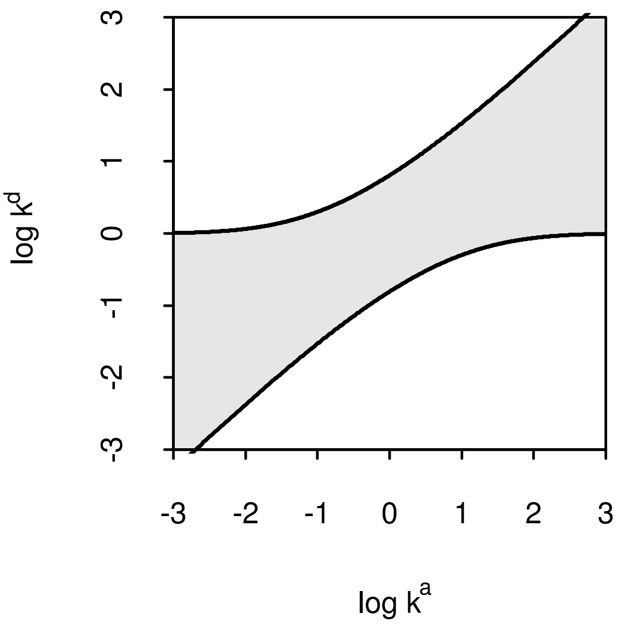
The range $[\theta_1^a, \theta_2^a]$ represents the range of preferences such that any decisionmaker with k^d in this range will delegate the decision to A. Since $\theta_1^a < 1 < \theta_2^a$ for any k^a, a neutral decisionmaker ($k^d = 1$) is willing to delegate decisions to an informed expert with any bias k^a. Further, since $L^a_*(y^a) < l^a(y^a) < L^a_{**}(y^a)$ for any y^a (Fact 2), substituting $y^a = \hat{t}^a$ into this inequality yields $\theta^a_1 < k^a < \theta^a_2$. A decisionmaker is willing to delegate decisions to an expert if $k^d = k^a$. More generally, if the expert is a liberal, any decisionmaker who is a less extreme liberal ($k^d \in [k^a, 1]$) will find this expert's service useful. If the expert is a conservative, any decisionmaker who is a less extreme conservative ($k^d \in [1, k^a]$) will find such an expert useful. In other words, the information of an expert is valuable to any decisionmaker whose bias is smaller than but similar to the expert's. Note, however, that this is a sufficient but not necessary condition for delegation to occur. Even a greater bias than the expert's, or an opposite bias, does not rule out delegation by the decisionmaker. As long as the decisionmaker is not extremely biased, he is willing to delegate decisions to make use of the expert's information.

Figure 1 illustrates how the region of delegation varies with k^a and k^d. In drawing this diagram we assume F^a_n is a normal distribution $N(0,1)$ and F^a_p is $N(1,1)$. The lower and upper boundaries of the shaded region are (the logarithms of) θ^a_1 and θ^a_2. Since $d\hat{t}^a/dk^a > 0$ and since L^a_* and L^a_{**} are strictly increasing functions (Fact 3), the boundaries are upward sloping in k^a. Thus, an expert with a more extreme preference for rejection has a greater chance of being delegated with the decision by decisionmakers who are conservatives. The intuition is as follows. For a decisionmaker who is a conservative, the uninformed decision is to reject. Delegating the decision to expert A makes a difference to the decisionmaker only if expert A decides to adopt. When the expert is more biased toward rejection, a decision to adopt requires more overwhelming evidence for the policy change having positive net benefit, which implies that more decisionmakers who are conservatives will find delegation to expert A acceptable.

The result that an expert with a more extreme preference will be acceptable to a wider class of less extreme but similarly biased decisionmakers offers an explanation for why it took President Nixon, a staunchly anti-communist hawk, to open the door to the international recognition of the People's Republic of China. Such episodes of policy reversals by "unlikely" parties or politicians have recently been explained by electorate

Figure 1

Region of delegation: the case of a single expert



uncertainty about the desirable policy outcomes and about the policy leanings of the party in charge (Cukierman and Tommasi, 1998). According to this theory, Nixon had the credibility to convince the public that the policy shift was not due to natural ideological tendencies of his party. Our delegation model offers a complementary explanation for this episode. In the early 1970's, mainstream politicians and the American public were still much against normalizing relations with communist China, but there were uncertainties in the international power play about the benefit and timing of legitimizing the communist government in China. Given his impeccable anti-communist record, Nixon was the right choice for envoy to explore the possibilities in China. As it turned out, Nixon's shift of policy toward China won over largely suspicious and unsure public opinion. Policy reversal by an extreme conservative carries weight among conservatives.

Of course an increase in k^a raises the lower boundary of delegation θ_1^a as well as the upper boundary θ_2^a. Although an expert with a greater bias for rejection is acceptable to a wider spectrum of conservative decisionmakers, fewer liberal decisionmakers will agree to delegate the decision to this expert. This poses a problem for an organization trying to recruit experts to ensure their use by a wide class of decisionmakers, because decisionmakers biased in opposite directions cannot be accommodated at the same time. We will show later that this problem is avoided by recruiting a team of experts with "balanced" preferences.

For any given expert with preferences given by k^a, Figure 1 shows the range of decisionmakers who will find such an expert's advice useful. For any decisionmaker with preferences given by k^d, the same figure shows the range of experts who will be useful to such a decisionmaker. Thus, a liberal decisionmaker ($k^d < 1$) will not benefit from the advice of an expert whose preferences are to the right of the lower boundary of Figure 1, and a conservative decisionmaker ($k^d > 1$) will not benefit from the advice of an expert whose preferences are to the left of the upper boundary in Figure 1. This is consistent with the observation that people have a tendency to rely on information from like-minded sources. According to our theory, a politically conservative decisionmaker listens to the Heritage Foundation (a conservative thinktank) not because he enjoys voices that agree with his own political inclinations, but because his decisions will be changed if the Heritage Foundation recommends a policy that is contrary to his preferences. Similarly, this politically conservative decisionmaker does not read *The New Republic* (a liberal publication) not because he dislikes reading dissenting opinion, but because whatever policy recommendations that emerge from this magazine will not change his prior sufficiently to alter his decisions. Our model offers a decision-theoretic explanation rather than a taste-based explanation for the demand for biased opinion.[8]

B. Value versus Influence

We distinguish between two aspects that make an expert useful in an organization: value and influence. An expert is "influential" if his service is of positive value to a wide range of decisionmakers in the organization. The extent of influence of an expert A is

[8] That the value of information lies in its potential to change a decision has been pointed out by, among others, Meyer (1991) and Calvert (1985). In different contexts, both authors demonstrate the value of introducing bias into the structure of information when information is coarse.

measured by the delegation range $[\theta_1^a, \theta_2^a]$ described above. Now we evaluate another aspect that makes an expert useful, namely, the value of his service to a decisionmaker with given preferences. Conditional on delegating the decision to expert A, the expected cost C^d in equation (1) measures the benefit from delegation to decisionmaker D. Taking derivatives and using the definition of $\hat{t}^a$, we find that dC^d/dk^a has the same sign as $(k^a - k^d)d\hat{t}^a/dk^a$. Since $d\hat{t}^a/dk^a > 0$, the expected cost C^d increases in k^a if and only if $k^a > k^d$, and C^d decreases in k^a if and only if $k^a < k^d$. In other words, the value of an expert's service to a decisionmaker falls as the expert's preferences diverge from the decisionmaker's. Not surprisingly, the value of an expert to a given decisionmaker is the greatest when the expert shares the same preferences as the decisionmaker.

An expert is useless if decisionmakers do not want to delegate their decisions to him. When recruiting an expert, an organization may want to ensure that a wide range of decisionmakers with different preferences will want to use the expert's service. However, there is a trade-off between recruiting an expert with wide influence and recruiting one with great value. An expert who is acceptable to many decisionmakers is not necessarily very valuable to those who use his service. Suppose that the likely decisionmakers in the organization are liberals ($k^d < 1$). To ensure that the expert within this organization is influential, the organization should pick an expert whose preferences are strongly biased toward adoption. But such choice also means that the expert is of small value to any given decisionmaker in the organization, because very often the strongly-biased expert will simply reinforce the tendency of the decisionmakers to adopt. Later we show that the same dilemma persists when expertise is offered by a team of experts instead of a single expert.

Another factor that affects the value an expert is the quality of his information. In our setup, we can model quality of information by considering a modification of the information structure available to expert A. Suppose that the expert observes his private signal with probability $1 - \pi^a$, and observes the true state with probability π^a. An increase in π^a represents a higher quality of A's information. With this modified information structure, the threshold for adoption $\hat{t}^a$ stays the same, but the expected cost to decisionmaker D from delegation becomes $(1-\pi^a)C^d$. Clearly, an increase in π^a increases the value from delegation for any given decisionmaker.

An improvement in the quality of information also affects the range of delegation $[\theta_1^a, \theta_2^a]$. With the modified information structure, the critical values for delegation are defined by:

$$\theta_1^a = (1-\pi^a)[\theta_1^a(1-F_n^a(\hat{t}^a)) + F_p^a(\hat{t}^a)];$$

$$1 = (1-\pi^a)[\theta_2^a(1-F_n^a(\hat{t}^a)) + F_p^a(\hat{t}^a)].$$

Differentiating these equations with respect to π^a shows that θ_1^a decreases and θ_2^a increases as π^a increases. Regardless of the preferences of expert A, his expertise has a greater chance of being utilized by a decisionmaker if the quality of his information is higher. An expert with extreme preferences tend to be influential among moderate and like-minded decisionmakers, but the value of his service is relatively low. In contrast, an expert with good information is both influential and valuable.

4. Delegating Decisions to a Team of Experts

When decisions are delegated to a single expert, this expert decides according to his own preferences, which do not necessarily accord with those of the decisionmaker. One way to control manipulation by a single expert is to play one expert against another. In other words, conflict of interests among the experts themselves may prevent the decisionmaker from being dominated by any single expert. An additional advantage from using more than one expert arises from potential gains from pooling diverse information. We illustrate these issues in simplest terms by considering a team of two experts.

An uninformed decisionmaker D considers whether to dictate the outcome or to delegate to a team of two experts, A and B. If delegation occurs, experts A and B face a problem of strategic information aggregation. Such a game is analyzed by Li, Rosen and Suen (forthcoming). For the purposes of the present paper, we focus on simple two-way voting equilibria, corresponding to types of two-way voting procedures. In "unilateral adoption," the policy change is adopted if there is at least one "adopt" vote. In "unilateral rejection," adoption requires two "adopt" votes. These two voting procedures have natural interpretations as two different "delegation mechanisms." Unlike in the case of a single expert, in delegating to a team of experts, it is no longer self-evident how the decisionmaker lets the experts have their say. Some degree of control and monitoring is necessary. The unilateral adoption and unilateral rejection procedures impose minimum structure on the game of strategic information aggregation between the two experts. They are easy to implement in practice, and provide a tractable and general enough framework for our analysis of delegation and decisionmaker-expert relationships.

The two delegation mechanisms define two different voting games between A and B. Suppose that there exists a pair of thresholds (t^a_*, t^b_*) that satisfy

$$\begin{aligned} l^a(t^a_*)L^b_*(t^b_*) &= k^a, \\ l^b(t^b_*)L^a_*(t^a_*) &= k^b. \end{aligned} \tag{2}$$

Similarly, suppose that a pair of thresholds (t^a_{**}, t^b_{**}) satisfy

$$\begin{aligned} l^a(t^a_{**})L^b_{**}(t^b_{**}) &= k^a, \\ l^b(t^b_{**})L^a_{**}(t^a_{**}) &= k^b. \end{aligned} \tag{3}$$

We use the following result by Li, Rosen and Suen (forthcoming).

PROPOSITION 3. *In the voting game with unilateral adoption, each expert $e = a, b$ votes "adopt" if and only if $y^e \geq t^e_*$. In the voting game with unilateral rejection, each expert $e = a, b$ votes "adopt" if and only if $y^e \geq t^e_{**}$.*

Under the assumption that l^e/L^e_* and l^e/L^e_{**} are increasing functions for $e = a, b$, each of the equilibrium described above is unique. Heuristically, Proposition 3 can be established by a pivotal voter argument. Under unilateral adoption, for example, expert A's vote matters only when B votes to reject. Based on the information that $Y^a = y^a$ and $Y^b < t^b_*$, expert A updates his posterior probabilities of the policy change having positive and negative present benefit to $\eta\gamma^a f^a_p(y^a)F^b_p(t^b_*)$ and $\eta(1-\gamma^a)f^a_n(y^a)F^b_n(t^b_*)$, where η is a normalizing factor. Comparing the relative costs of false adoption and false rejection then results in a threshold for adoption as described in equation (2).

A. Balance

Let C_*^d be the expected cost to decisionmaker D of delegating his decision to a team of experts A and B under unilateral adoption. We have:

$$C_*^d = k_1^d[1 - F_n^a(t_*^a)F_n^b(y_*^b)] + k_2^d F_p^a(t_*^a)F_p^b(t_*^b). \tag{4}$$

Suppose the decisionmaker is a liberal. He prefers delegating the decision to this team to making an uninformed adoption if $k_1^d \geq C_*^d$. This is equivalent to the condition that k^d be greater than the critical value $\theta_* = L_*^a(t_*^a)L_*^b(t_*^b)$.

Similarly, let C_{**}^d be the expected cost under the unilateral rejection delegation mechanism. We have:

$$C_{**}^d = k_1^d[1 - F_n^a(t_{**}^a)][1 - F_n^b(t_{**}^b)] + k_2^d[1 - (1 - F_p^a(t_{**}^a))(1 - F_p^b(t_{**}^b))]. \tag{5}$$

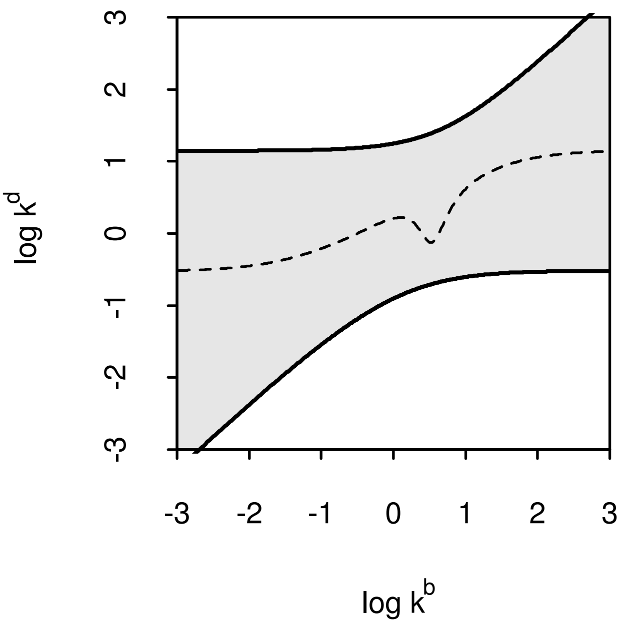
When the decisionmaker is a conservative, he prefers delegating the decision to this team to making an uninformed rejection decision if $k_2^d \geq C_{**}^d$. This is equivalent to requiring that k^d be smaller than the critical value $\theta_{**} = L_{**}^a(t_{**}^a)L_{**}^b(t_{**}^b)$. Note that $\theta_* < 1 < \theta_{**}$ (Fact 1). We summarize the results in the following proposition:

PROPOSITION 4. *There exist two critical values $\theta_* < \theta_{**}$, such that decisionmaker D prefers an uninformed adoption decision to delegation under unilateral adoption if he is sufficiently liberal ($k^d < \theta_*$), prefers an uninformed rejection decision to delegation with unilateral rejection if he is sufficiently conservative ($k^d > \theta_{**}$), and prefers delegation if k^d is in between these critical values.*

Although making an uninformed decision is dominated by delegation for decisionmaker D when $k^d \in [\theta_*, \theta_{**}]$, the above proposition does not directly compare C_*^d and C_{**}^d. Such comparisons would depend on the distribution functions of the data. Figure 2 shows the region of delegation for a team of experts A and B, with k^a held constant at $\log k^a = 0.5$. The lower and upper solid lines are the graphs of $\log \theta_*$ and $\log \theta_{**}$, respectively. The signals observed by the experts are assumed to be distributed $N(0,1)$ or $N(1,1)$, depending on the true state. Under this assumption about the data distributions, the decisionmaker prefers unilateral adoption to unilateral rejection if and only

Figure 2

Region of delegation: the case of two experts



if $\log k^d$ is below the dashed line. Although this line is not monotonic in k^b, it always lies between $\log \theta_*$ and $\log \theta_{**}$. Thus, if $k^d < \theta_*$, decisionmaker D prefers unilateral adoption to unilateral rejection. Since D also prefers making an uninformed adoption decision to unilateral adoption when $k^d < \theta_*$, this means that θ_* is indeed the lower bound for which delegation will occur. Similarly, with normally distributed signals, θ_{**} is the indeed upper bound for which delegation will occur. Nevertheless, with arbitrary distributions satisfying the monotone likelihood ratio property, we cannot rule out the possibility that decisionmaker D prefers delegation under unilateral rejection to making an informed adoption decision when $k^d < \theta_*$. Similarly we cannot prove that decisionmaker D will not prefer delegation under unilateral adoption to making an informed rejection decision when $k^d > \theta_{**}$. In light of these observations, the range of delegation $[\theta_*, \theta_{**}]$ should be viewed as a conservative bound.

In deriving Proposition 4, we have assumed that the decisionmaker can credibly commit to not overruling the decision by the team after delegation. It turns out that if the decisionmaker is willing to delegate the decision under a given mechanism, then he will not have incentives to overrule the team's decision when he does not monitor how the team reaches the decision. For example, suppose that the decisionmaker agrees to delegate the decision under unilateral adoption. Then, after learning that the team has made the rejection decision, D infers that $y^a < t^a_*$ and $y^b < t^b_*$. The decisionmaker has no incentive to overrule this decision, because overruling requires that $k^d < \theta_*$, in which case D would not have agreed to delegate in the first place. Similarly, after learning that the team has made the adoption decision, D infers that $y^a \geq t^a_*$ or $y^b \geq t^b_*$, or both. Overruling this decision requires $k^d > [1 - F^a_g(t^a_*)F^b_g(t^b_*)]/[1 - F^a_n(t^a_*)F^b_n(t^b_*)]$, but the opposite is true because D prefers delegation to making an uninformed rejection decision. Therefore, as in the case of a single expert, for a given delegation mechanism the very willingness of D to delegate the decision is itself a credible commitment to not overruling the team's decision.[9] Moreover the proceeding analysis implies that if the procedure itself is optimally chosen, the decisionmaker has no incentive to overrule the team's decision if k^d falls into the delegation range $[\theta_*, \theta_{**}]$.

Several corollaries are immediately clear from Proposition 4. First, since $\theta_* < 1 < \theta_{**}$ for any k^a and k^b, a neutral decisionmaker will always prefer delegation to making an uninformed decision. Second, since $\theta_* < k^a, k^b$ and $\theta_{**} > k^a, k^b$, any decisionmaker with preferences k^d between k^a and k^b will always prefer delegating the decision to the team of experts A and B to making the decision himself. Third, since a team of two experts has access to more information than a single expert, one expects that the delegation range is larger with two experts than with one expert. To verify this claim, note that from $l^a(\hat{t}^a) = k^a$ and $l^a(t^a_*)L^b_*(t^b_*) = k^a$, we have $t^a_* > \hat{t}^a$. Substituting $L^b_*(t^b_*) = k^a/l^a(t^a_*)$ into the definition of θ_*, we have $\theta_* = k^a L_*(t^a_*)/l(t^a_*)$. In contrast, $\theta^a_1 = k^a L_*(\hat{t}^a)/l(\hat{t}^a)$. Since $t^a_* > \hat{t}_a$, the assumption that l^a/L^a_* is a strictly increasing function implies that

[9] The resemblance between delegating to two experts and delegating to a single expert in terms of commitment to not overruling the decision breaks down if D monitors how the team makes the decision. For example, suppose that $k^a = k^b$ and the two signals have the same conditional distributions. We can easily verify that there is an interval of k^d such that D will agree to delegate under unilateral adoption, but will have incentives to overrule if the team's adoption decision is unilateral, though not if the team reaches either adoption or rejection decisions unanimously.

$\theta_* < \theta_1^a$. A similar argument establishes that $\theta_{**} > \theta_2^a$. Thus, a team of experts A and B is acceptable to a wider range of decisionmakers than is either of them alone. ¿From the decisionmaker's point of view, adding a second expert B cannot reduce his willingness to delegate the decision. In the worst cases when k^b is either close to zero or infinity, the extreme expert can be rendered irrelevant by an appropriate choice of the delegation mechanism. For example, if expert B is an extreme liberal (k^b close to zero), the decisionmaker can choose unilateral rejection so that delegating the decision to the team of experts A and B is equivalent to delegating to just A.

In Li, Rosen and Suen (forthcoming), we show that, under either unilateral adoption or unilateral rejection, as k^b increases, expert B raises his threshold of adoption while expert A lowers his in response. The overall effect of this change on the range of delegation is summarized in Proposition 5.

Proposition 5. *For any fixed k^a, as k^b increases, both the lower bound and the upper bound of the delegation range $[\theta_*, \theta_{**}]$ rise.*

The proof of Proposition 5 is in the appendix. The implication of this proposition is that, other things equal, a team with an expert who has more extreme preferences for rejection is more widely acceptable among decisionmakers who are conservatives, but is less widely acceptable among decisionmakers who are liberals.

Since different decisionmakers have different preferences, decisionmakers biased in opposite directions cannot be accommodated at the same time by any single expert. This problem can be avoided with two experts. An organization can ensure a wide use of delegation by different types of decisionmakers if a team of two experts have extreme and opposite preferences. Such a balanced team of radicals will have a wider delegation range than a one-sided team of moderates. To see this, consider a team of two experts A and B with moderate preferences k^a and k^b, with $k^a < k^b$. Let $[\theta_*, \theta_{**}]$ be the corresponding delegation range. Any decisionmaker with preference k^d sufficiently biased toward rejection ($k^d > \theta_{**}$) prefers making an uninformed decision to delegating the decision to this team. This problem can be overcome by recruiting another expert with a higher k^b. However, doing so without changing k^a will make the team less acceptable to decisionmakers who are liberals. The solution is to reduce k^a while increasing k^b, that is, recruit experts who are more extreme in opposite directions. Consider another team of two experts A_1 and B_1 with extreme and opposite preferences, say $k^{a_1} < \theta_*$ and $k^{b_1} > \theta_{**}$. Then, since any decisionmaker with preferences $k^d \in [k^{a_1}, k^{b_1}]$ is willing to delegate the decision to this other team, the range of delegation for the second team with experts A_1 and B_1 strictly contains the range of delegation for the first team with experts A and B.

The reason that a balanced team has a greater use of delegation than a one-sided team has to do with the decisionmaker's choice of delegation mechanism. We have assumed that the decisionmaker can specify the voting procedure (unilateral adoption or unilateral rejection) in delegating to a team of experts. When the decisionmaker is a liberal, his natural ally is the expert who has the same bias relative to the other expert, and the delegation mechanism of unilateral adoption protects the interests of the decisionmaker by giving the control of decisionmaking in the team to his ally. Similarly, when the decisionmaker is a conservative, he relies more on the expert who is relatively biased toward rejection, and the procedure of unilateral rejection protects the interests of the decisionmaker.

The claim has often been made that "competition of ideas" by advocates with opposing interests is the best way to bring out the true merits of contrasting views in a debate. The claim has been cited as one advantage of the adversarial judicial system of the Anglo-American kind over the inquisitorial system found in continental Europe (see, for example, Milgrom and Roberts, 1986). In our model the benefit of having balanced interests on the expert team does not come from forcing experts with opposing interests to compete with each other. Also, the issue of balance in an expert team has recently been studied by Krishna and Morgan (2001). As in the present paper, their model of expertise deals with two experts on a team having different preferences regarding the decision; but unlike our model, these experts have the same data. They show that there is benefit for a decisionmaker to consult both experts (instead of consulting the one whose preference is closer to the decisionmaker) only when they are biased in opposite directions relative to the decisionmaker. The apparent benefit from balancing the expert team with opposite biases arises because eliciting private information is easier for the decisionmaker when the two experts are opposed in their interests. In our model, balancing the expert team makes the delegation more likely for a wider range of biases of the decisionmaker, because the decisionmaker can always adopt the appropriate delegation mechanism to rely on the more "loyal" expert.

However using a balanced team of experts with extreme preferences is not costless. Such a team may be very influential in the sense that it is acceptable to a wide range of decisionmakers. But the value of its expertise, while positive, is generally low. Greater conflict of interests within a balanced team of extremists makes information transmission less efficient. As a result the quality of the team's decision deteriorates. To see this point, consider the expected cost for decisionmaker D if he uses a team of experts A and B. Suppose $k^a < k^d < k^b$. Under unilateral adoption, this expected cost is given by equation (4) above. If a balanced but more extreme team of experts (with $k^{a_1} < k^a$ and $k^{b_1} > k^b$) is used, then the adoption thresholds t_*^a falls and t_*^b rises. Since $\partial C_*^d / \partial t_*^a$ has the same sign as $k^a - k^d$ and $\partial C_*^d / \partial t_*^b$ has the same sign as $k^b - k^d$, the expected cost C_*^d for decisionmaker D unambiguously rises. The same reasoning shows that the expected cost for decisionmaker D under unilateral rejection C_{**}^d also rises when the team of experts becomes more biased in opposite directions. Thus, there is again a trade-off between influence and value for an expert team. A team that is acceptable to a wide class of decisionmakers may not produce decisions that are highly valuable.

B. Neutrality

For a given decisionmaker D, the ideal team of experts should have both experts with preferences identical to D's. However, the analysis above shows that having balanced preferences in the expert team makes it widely acceptable to different decisionmakers. Thus, there is a benefit of having some degree of conflict in the team. Consider, then, a situation in which decisionmaker D already has expert A at hand and is thinking about bringing another expert, say B, to the team. Suppose that $k^d < k^a$. Does decisionmaker

D want the second expert B to have the same preference as himself ($k^b = k^d$)?

The answer is to this question is no. To see this, decompose dC_*^d/dk^b into two parts:

$$\frac{dC_*^d}{dk^b} = \frac{\partial C_*^d}{\partial t_*^a}\frac{dt_*^a}{dk^b} + \frac{\partial C_*^d}{\partial t_*^b}\frac{dt_*^b}{dk^b}. \tag{6}$$

The second term of equation (6) is zero at $k^b = k^d$ because $\partial C_*^d/\partial t_*^b$ has the same sign as $k^b - k^d$. Since $k^d < k^a$, and $dt_*^a/dk^b < 0$, we get $dC_*^d/dk^b < 0$. Thus, decisionmaker D does not want the new expert B to have a preference k^b identical to his. The reason is that doing so will force the existing expert A to be more extreme and therefore distort A's information. Conflict of interests exists between experts within the team, as well as between expert B and the decisionmaker. Since the cost of having an expert B just slightly less biased (toward adoption) than himself is of second order importance, the decisionmaker will want the second expert to have the appearance of neutrality. This reduces t_*^a and makes expert A less manipulative with his information.

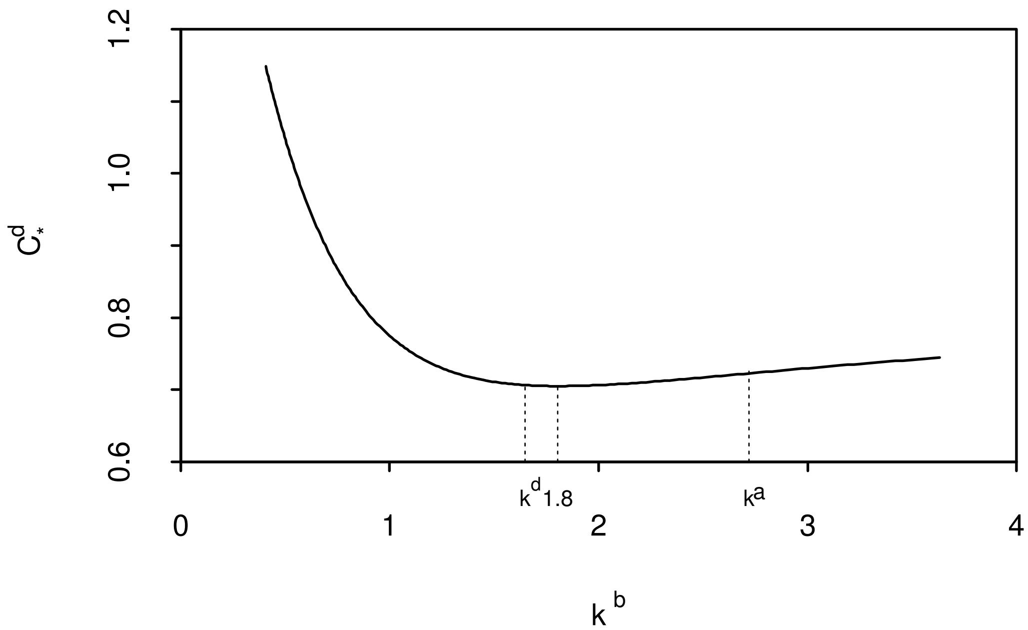
With some additional assumptions it can be shown that the best expert B for the decisionmaker to recruit is one with $k^b \in (k^d, k^a)$. We make the assumption that the data of A and B have the same conditional distributions; this ensures that the effect of B's preferences k^b on his threshold t_*^b is greater in magnitude than the effect of k^b on A's threshold t_*^a. We also assume that $k^d > \theta_*$. The latter assumption is innocuous, as decisionmaker D would rather make an uninformed adoption decision if this condition is not satisfied. The proof of Proposition 6 is in the appendix.

PROPOSITION 6. *Suppose $k^d < k^a$. (a) For $k^b \leq k^d$, expected cost C_*^d for the decisionmaker increases as k^b falls. (b) For $k^b \geq k^a$, C_*^d increases as k^b rises, assuming that experts A and B have the same conditional signal distributions and that $k^d \geq \theta_*$.*

A similar argument leads to the conclusion that $dC_{**}^d/dk^b < 0$ for all $k^b \leq k^d$, and $dC_{**}^d/dk^b > 0$ for all $k^b \geq k^a$ when $k^d \leq \theta_{**}$. Thus, regardless of whether the delegation mechanism is unilateral adoption or unilateral rejection, as long as the decisionmaker prefers delegation to making uninformed decisions, expected cost is minimized by choosing k^b somewhere between k^d and k^a. This means that when the existing expert A is a

Figure 3

Expected cost for the decisionmaker is minimized by choosing $k^b \in (k^d, k^a)$



conservative relative to decisionmaker D, the decisionmaker will want a second expert B who is less conservative than A but is more conservative than himself. We illustrate this in Figure 3, which shows the expected cost C^d_* as a function of k^b, holding k^a constant at $k^a = 2.72$. We assume $k^d = 1.65$, so that decisionmaker D is less biased toward rejection than is expert A. The data of the experts are assumed to be normally distributed with a mean shift corresponding to the true state. Figure 3 shows that decisionmaker D can minimize expected cost by recruiting an expert B with $k^b = 1.80$. Such an expert is less biased toward rejection compared to expert A but is more biased toward rejection compared to decisionmaker D.

The logic of Proposition 6 does not depend on whether the decisionmaker is informed or not. In some situations a decisionmaker may sit in the committee himself or delegate an expert to sit in it. Proposition 6 suggests that even if the decisionmaker is equally well informed as the expert, he has an incentive to delegate the expert to sit in the committee on his behalf in order to reduce the conflict of interests within the committee. By appointing someone with preferences more similar to other committee members' preferences, the decisionmaker commits himself to be less partisan and thus improves the pooling of information within the committee.

Proposition 6 offers a theory of neutrality in collective decisionmaking. This theory is driven both by conflict in interests between the decisionmaker and the experts, and by the strategic manipulations of the two self-interested experts in the team. While we have illustrated this point under the assumption that the two experts play a simple two-way voting game, the same conclusion holds when more sophisticated mechanisms are considered.[10] For example, a decisionmaker or his delegate may make a recommendation and a higher authority ultimately determines the outcome based his own private information and on the recommendation.[11] In this case, it is possible for the decisionmaker or his delegate to express different degrees of support for the proposal, instead of just a "yes" or "no" recommendation. A different decision rule can be used depending on what recommendation is given. As long as conflict of interests exists between the decisionmaker and the higher authority, our theory suggests that the decisionmaker will recruit a delegate whose preferences are closer to those of the higher authority. This ensures that the higher authority will be less skeptical of the recommendation, and therefore rely less on his own preferences and more on the recommendation in making the final decision. The decisionmaker benefits from the resulting improvement in the efficiency of information aggregation.[12]

C. Are Two Experts Better than One?

In concluding that the best expert for decisionmaker D to recruit is one with preferences

[10] For a characterization of outcomes of these mechanisms, see Li, Rosen and Suen (forthcoming).

[11] Letterie and Swank (1997) and Letterie, Swank and van Dalen (2000) analyze the choice of policy advisors in related contexts and arrive at conclusions similar to ours.

[12] Inefficient information aggregation arises for two reasons: continuous information is coarsened into discrete recommendations, and the thresholds for making different recommendations are chosen strategically. The result in Proposition 6 implies that recruiting a delegate with preferences closer to the higher decisionmaker's preferences would reduce the inefficiency from strategic choice of thresholds. An additional gain not related to Proposition 6 is that lesser conflict of interests between the expert and the higher decisionmaker would allow the expert to make finer gradations in his recommendation and hence reduce the inefficiency from information coarsening.

between those of the decisionmaker and the existing expert A, we have assumed that D cannot exclude A in delegating the decision. Is it possible that the conflicts between D and A are so large that D wants to recruit an expert B and delegate to B alone?

If the delegation mechanism cannot be chosen, then having two experts can be worse than having just one for the decisionmaker. For example, a liberal decisionmaker prefers delegating to an expert with moderate preferences than to a team consisting of this expert and a hard-nosed conservative, if the team has to use the unilateral rejection mechanism. This is because the unilateral rejection mechanism allows the hard-nosed conservative member of the team to make the rejection decision by himself with little input from the moderate member.

Proposition 6 can be used to argue that this is not the case, as long as the decisionmaker can select the voting procedure in delegating the decision to the team of A and B. To see this, suppose that $k^d \leq k^b$ and vary the preferences of expert A. If $k^a = 0$, then under unilateral rejection, the team with A and B makes the same decisions as B alone, because A will always choose to adopt. Since $dC^d_{**}/dk^a < 0$ for $k^a \leq k^d$, D prefers the team to B alone for all $k^a \leq k^d$. That is, from the decisionmaker's point of view, keeping a liberal expert A on board is better as long as the delegation mechanism is unilateral rejection. On the other hand, if $k^a = \infty$, then under unilateral adoption the team makes the same decisions as B alone. Under the same assumptions as in Proposition 6, we have $dC^d_*/dk^a > 0$ for any $k^a \geq k^b$, which implies that under unilateral adoption the team is better than B alone.[13] Thus, keeping a conservative expert A in the team is better as long as unilateral adoption is the procedure. Finally, if $k^d < k^a < k^b$, then the proceeding argument implies that the team is better than A alone, but since A alone

[13] A numerical example shows that if the assumptions are not satisfied, using B alone is better. Suppose that $k^d = 1.65$ and $k^b = 2.72$. For B, the conditional distributions are $N(0,1)$ and $N(1,1)$. If D delegates to B alone, we have $\hat{t}^b = 1.5$, and $C^d = 0.80$. Suppose that $k^a = 2.72$, but the conditional distributions of A's signal are $N(0,1)$ and $N(0.1,1)$ so that A's signal is much less informative than B's. When they form a team, unilateral adoption is better than unilateral rejection for D. But even under unilateral adoption, we have $t^a_* = 1.34$, $t^b_* = 1.52$, and $C^d_* = 0.87 > C^d$. The intuition is that under unilateral adoption B votes to adopt more cautiously than when he alone is delegated with the decision (that is $t^b_* > \hat{t}^b$). From the liberal decisionmaker's point of view, teaming B with A makes B too conservative. This adverse effect is partly compensated by the fact that A votes to adopt sometimes. But since A's signals are not good, it is not of much help.

is better than B alone when $k^a < k^b$, the team is better than B alone. Thus, under the same assumptions as in Proposition 6, D will never find it optimal to exclude A in delegating the decision, regardless of how much A's preferences differ from his own. Combined with our earlier analysis, we have therefore established that a team of two experts has not only a greater influence than either of the two experts alone, but also a greater value to any given decisionmaker.

5. Informed Delegation

So far we have assumed that the decisionmaker is uninformed, and the delegation decision can be based only on the extent of conflicts of interests between himself and the experts. In practice, decisionmakers often have their own source of information about the decision, and seek expert advice only when needed. In this section, we consider delegation by a privately-informed decisionmaker to a single expert. The delegation decision can be conditioned on the decisionmaker's information, as well as on preferences of the decisionmaker and the expert.

If the decisionmaker's information were known to the expert, informed delegation would be no different from uninformed delegation considered in the previous sections: we only need to change the decisionmaker's prior to the posterior given his information, and all the analysis follows through. The assumption that the decisionmaker's information is private means that the very act of delegating the decision communicates his information to the expert. By using selective delegation mechanisms, the decisionmaker can reduce manipulation by the expert in the event of delegation.

A. Second opinions

Suppose that decisionmaker D is more liberal than expert A ($k^d < k^a$). If D's information favors adoption, then it is natural for the decisionmaker to make the adoption decision. Consulting the expert seems both unnecessary because his own information supports his bias, and risky because A is relatively prone to rejection. On the other hand, if D's own information argues against adoption, it seems prudent for D to get a second reading by delegating the decision to A.

Formally, consider the following delegation mechanism with adoption control: D delegates the decision to A only if y^d falls below some threshold t_*^d, and adopts otherwise. This is equivalent to a procedure in which one vote from either D or A is sufficient to adopt, except that voting is sequential rather than simultaneous. Upon delegation, expert A infers $y^d < t_*^d$, and makes the decision based on this inference and on his own data y^a. Thus expert A decides in exactly the same way he would have voted if he is a pivotal voter in a team with unilateral adoption. The optimal decision for A is to adopt if and only if $y^a \geq t_*^a$, where the threshold t_*^a satisfies

$$l^a(t_*^a)L_*^d(t_*^d) = k^a.$$

Anticipating this, decisionmaker D sets the threshold t_*^d of delegation according to

$$l^d(t_*^d)L_*^a(t_*^a) = k^d.$$

Thus, the mechanism with adoption control is formally equivalent to unilateral adoption.[14] The expected cost to the decisionmaker in this case is given by

$$C_*^d = k_1^d(1 - F_n^d(t_*^d)F_n^a(t_*^a)) + k_2^d F_p^d(t_*^d)F_p^a(t_*^a).$$

In the symmetric situation where the decisionmaker is more conservative than expert A ($k^d > k^a$), the mechanism with rejection control takes the following form: D delegates only if y^d exceeds some threshold, and rejects otherwise. This is formally equivalent to unilateral rejection. The threshold of delegation for the decisionmaker t_{**}^d and the threshold t_{**}^a for expert A satisfy

$$l^d(t_{**}^d)L_{**}^a(t_{**}^a) = k^d,$$
$$l^a(t_{**}^a)L_{**}^d(t_{**}^d) = k^a.$$

The expected cost to decisionmaker D in this case is given by

$$C_{**}^d = k_1^d[1 - F_n^d(t_{**}^d)][(1 - F_n^a(t_{**}^a)] + k_2^d[1 - (1 - F_n^d(t_{**}^d))(1 - F_n^a(t_{**}^a))].$$

[14] The equivalence between simultaneous voting and sequential voting in binary elections has been pointed out by Dekel and Piccione (2000) and Li, Rosen and Suen (forthcoming). This equivalence implies that the decisionmaker never has incentives to overrule the expert's decision after delegation.

In the case of uninformed decisionmaker, when the conflict of interests is sufficiently great between the decisionmaker and the expert, delegation will never occur. Here, since D can always rely on his own information, the never-delegate option seems even more attractive. However, we can show that by using the delegation mechanisms, an informed decisionmaker always benefits by having the option of seeking a second opinion from the expert, regardless of the preference conflict between D and A. In particular, D retains control by giving the expert only the authority of granting a second chance to adopt project if the expert is more conservative than himself. Similarly, he retains control by giving the expert only the veto power to kill a project if the expert is more liberal than he is. Such combination of delegation and control dominates making the decision without consulting the expert, regardless of the extent of conflicts.

For the following proposition, let C^d be the expected cost to the decisionmaker who never delegates. We have seen earlier that in this case decisionmaker D uses the threshold $\hat{t}^d$ which satisfies $l^d(\hat{t}^d) = k^d$. Thus,

$$C^d = k_1^d(1 - F_n^d(\hat{t}^d)) + k_2^d F_p^d(\hat{t}^d).$$

PROPOSITION 7. *If the decisionmaker is more liberal than the expert ($k^d < k^a$), then the mechanism with adoption control is better than no delegation ($C_*^d < C^d$). If the decisionmaker is more conservative than the expert $k^d > k^a$), then the mechanism with rejection control is better than no delegation ($C_{**}^d < C^d$).*

The proof of the above result is straightforward. Compare C_*^d and C^d. When k^a becomes arbitrarily large, expert A almost always chooses to reject upon delegation. Since delegation is essentially the same as rejection, decisionmaker D sets t_*^d very close to $\hat{t}^d$. This means C_*^d is arbitrarily close to C^d. Moreover, since $dC_*^d/dk^a > 0$ for all $k^a > k^d$, we have $C_*^d < C^d$ for all $k^a > k^d$. By a similar argument, $C_{**}^d < C^d$ for all $k^a < k^d$.

In the case of uninformed decisionmaker, we have defined the influence of an expert as the range $[\theta_1^a, \theta_2^a]$ of D's preference such that delegation occurs. With an informed decisionmaker, the influence cannot be defined in the same way, as D always benefits from having the delegation option. Instead, we may take D's threshold in seeking second opinions as a measure of A's influence. For the delegation mechanism with adoption control, D delegates if $y^d < t_*^d$, so a greater t_*^d means a more influential expert A. Similarly, for the mechanism with rejection control, D delegates if $y^d > t_{**}^d$, so a smaller t_{**}^d means a greater influence for A.

As in the case of uninformed delegation, two factors are important in determining the influence of an expert: bias and expertise. In Li, Rosen and Suen (forthcoming), we have made comparative statics analysis of the voting equilibria in two-expert teams, regarding changes in conflict of interests and quality of expertise. Since the mechanism with adoption (rejection) control is formally equivalent to the unilateral adoption (rejection) procedure in a two-expert team, the following effects of bias and expertise on the influence of an expert can be established in the same way. If D is relatively liberal and seeks second opinion from A only when his own information is against adoption, the need for D to retain control over the adoption decision is smaller if A is less conservative. That is, we expect t_*^d to increase when k^a decreases—a more liberal expert has a greater influence among liberal decisionmakers. For the same reason, this more liberal expert is less influential among conservative decisionmakers: t_{**}^d also increases as k^a increases. On the other hand, a higher quality of expertise implies that the expert is influential for both liberal and conservative decisionmakers. We can model quality of expertise in the same way as in the case of uninformed decisionmakers: if A observes his private signal with probability $1 - \pi^a$ and the true state with probability π^a, then an increase in π^a represents a higher quality of A's information. We can show that t_{**}^d increases and t_{**}^d decreases with an increase in π^a. Thus, regardless of the bias of the expert, a higher quality of his information makes him a more influential source of second opinion among decisionmakers of all preferences.

B. Control

When the decisionmaker is a liberal relative to the expert, D wants to retain control by keeping the option of unilateral adoption. The opposite is true when D is a conservative relative to A. It turns out that adopting a mechanism that delegates to the expert only when the evidence y^d is not conclusive either way accommodates both needs. By retaining the option of making both decisions based on his own information without consulting the expert, the decisionmaker can reduce manipulation by the expert and increases the value of his expertise.

Formally, suppose that decisionmaker D delegates the decision to expert A only when he is not sure, that is when his private evidence is relatively uninformative ($y^d \in [t_1^d, t_2^d]$). Upon delegation, expert A infers that $y^d \in [t_1^d, t_2^d]$. Then the optimal decision for A is to adopt if and only if $y^a \geq t^a$, where the threshold t^a satisfies

$$l^a(t^a)\mathcal{L}^d(t_2^d, t_1^d) = k^a.$$

Given this, decisionmaker D chooses to reject if $y^d < t_1^d$, adopt if $y^d > t_2^d$, and delegate if $y^d \in [t_1^d, t_2^d]$, where t_1^d and t_2^d satisfy:

$$l^d(t_1^d)L_{**}^a(t^a) = k^d,$$
$$l^d(t_2^d)L_*^a(t^a) = k^d.$$

The expected cost to D in this case is given by

$$\tilde{C}^d = k_1^d[1-F_n^d(t_2^d)+(F_n^d(t_2^d)-F_n^d(t_1^d))(1-F_n^a(t^a))]+k_2^d[F_p^a(t^a)(F_p^d(t_2^d)-F_p^d(t_1^d))+F_p^d(t_1^d)].$$

We have the following proposition (the proof is in the Appendix).

Proposition 8. *Delegating the decision with both adoption and rejection controls is better than the delegation mechanisms with only adoption or rejection control ($\tilde{C}^d < C_*^d$ if $k^d < k^a$ and $\tilde{C}^d < C_{**}^d$ if $k^d > k^a$).*

Delegating the decision only when his own information is not sure allows the decisionmaker to retain control of both adoption and rejection decisions. Proposition 8 shows that this mechanism directly benefits D compared to the mechanisms that retain the option of making the one decision that he is afraid of losing control of. Suppose that D is a liberal relative to A. In retaining the option of unilateral adoption, the decisionmaker anticipates the tendency of A to exaggerate evidence for rejection by using a low threshold of adoption. This has the effect of motivating the expert to manipulate his information and exaggerate the difference between his preferences and those of the decisionmaker. In contrast, the mechanism with both adoption and rejection controls allows the decisionmaker to soften his position when he delegates.[15] More information is communicated from D to A in the event of delegation, which reduces the manipulation of the expert and increases the value of his expertise, ultimately benefiting the decisionmaker.

Combining Proposition 8 with Proposition 7, we find that $\tilde{C}^d < C^d$ for all k^a and k^d. An informed decisionmaker can always gain by selective delegation, that is, delegating the decision to an expert only when his own evidence is so weak that it warrants a second opinion. Another way to implement selective delegation is the following. Decisionmaker D asks expert A to give a "adopt" or "reject" recommendation. Decisionmaker D adopts if and only if y^d exceeds the threshold t_1^d when A recommends adoption, and he adopts if and only if y^d exceeds a higher threshold t_2^d when A recommends rejection. In this way, decisionmaker D retains control over the final decision by consulting his own evidence instead of following the expert's advice all the time. Such control increases the value of expertise to the decisionmaker.

6. Conclusion

As a model of delegation and expertise, the novelty of this paper is to consider an environment with self-interested and privately-informed decisionmakers and experts, where the value of expertise depends both on how likely delegation occurs and how beneficial delegation is when it does occur, and where conflicts in interests exist both between the decisionmakers and the experts, and between the experts on a team. Our model allows us to consider a host of issues, including the trade-off between the influence and the value of experts, the balance of different points of views in an expert team, and the control of the decisionmaking process in delegation. The overall theme of the paper has been the interaction between the need for the decisionmaker to safeguard own interests and the need to exploit expertise. Controlling the decisionmaking process, through the choice of procedure or through conditioning the delegation decision on the decisionmaker's own

[15] The proof of Proposition 8 implies that $t_1^d < t_*^d < t_2^d$, and $t^a < t_*^a$.

information, turns out to be an effective way for the decisionmaker to strike a balance between these two opposing needs.

Related to the issues of delegation is the extensive literature on how to elicit private information from experts. The canonical signaling model is Crawford and Sobel (1982) (see also Green and Stokey, 1980), where a decisionmaker makes a choice in response to reported information of an expert. Gilligan and Krehbiel (1989) and Austen-Smith (1990) apply the signaling model to agenda-setting in legislatures. Krishna and Morgan (2001) study the case of multiple experts, but unlike the present model, the experts have identical information. Another recent paper on the problem of multiple experts is Ottaviani and Sorensen (1999); in their model the experts are concerned with making recommendations that are validated ex post. Milgrom and Roberts (1986) (see also Shin, 1994) study the situation where expert's information can be concealed but cannot be distorted. The setup of the present paper is closely related to Duggan and Martinelli (1999) and, especially, Li, Rosen and Suen (forthcoming), but their analysis is limited to a committee setting with no explicit role for delegation.

Economic analysis of delegation starts from that of authority. An earlier contribution was made by Simon (1951), who defines authority as the right to choose from a set of actions. Aghion and Tirole (1997) distinguish formal and real authority, where the focus is on the role of private information in decisionmaking. Their paper models delegation as credibly giving up control by a decisionmaker in order to encourage an expert to acquire relevant information, and suggests that the extent of conflict of interests between the decisionmaker and the expert systematically affects the tradeoff for the decisionmaker between loss of control (delegation) and loss of information (dictation). When conflicts are great, delegation tends to be a bad choice both because the loss of control means greater harm to the decisionmaker, and because a biased expert is unlikely to be swayed even if better informed. On the other hand, delegation tends to dominate dictation when conflicts are relatively small, because to the decisionmaker, loss of control is less harmful and the benefit of having a more informed expert is greater (so long as better information reduces the impact of conflicts rather than aggravates it.)

The above comparative statics with respect to extent of conflicts has been suggested in different contexts. For example, Gilligan and Krehbiel (1987) show that the "closed rule" used in U.S. Congress, under which an uninformed legislature can only veto but not amend a proposal of a committee, is better than making an uninformed decision for the legislature when its interests do not conflict too much with those of the committee. As in Aghion and Tirole, Gilligan and Krehbiel stress the informational advantage of delegation, but the same comparative statics result should hold if expertise is exogenously given. That is, instead of assuming that the expert acquires private information when delegated with the right to make the decision, one can imagine that the expert's information is already acquired but it can be utilized only under delegation. This point has been made by Krishna and Morgan (2000) and Dessein (2001). These authors further demonstrate that delegation is optimal when the extent of conflict is relatively small, even if instead of making an uninformed decision (dictation), the decisionmaker is allowed to use "communication," under which the expert is asked for a recommendation (but the decisionmaker is not committed to follow the recommendation). Communication improves upon dictation, but there is still a loss of information because the expert will strategically manipulate his recommendation to the decisionmaker. On the other hand, the advantage of delegation is strengthened if the decisionmaker can restrict the set of choices for the expert in delegating the decision (Holmstrom, 1984; Melumad and Shibano, 1991; Armstrong, 1994; Dessein, 2001).

There are several directions to further develop the present model of delegation and expertise. One is to relax the assumption that preferences of decisionmakers and experts are common knowledge. Another interesting extension is to consider the incentives for experts to improve the quality of their expertise. Such incentives have been investigated by Li (2001), but in a committee decisionmaking environment with public information. It can also be fruitful to consider the issue of paying for expertise. Organizations often hire external consultants to provide expert opinion on a case basis. Monetary incentives to elicit information from self-interested experts have been ignored in our analysis. It can be shown that appropriate ex post money transfer mechanisms (after private data are observed) can be used to provide incentives for truthful revelation of private information (Groves, 1973; d'Aspremont and Gerard-Varet, 1979). However, these mechanisms require ex ante commitment by all parties (before private information is observed), which may not be a realistic assumption in a real-life delegation environment. Paying for expertise without ex ante commitment is an interesting issue to study. Lastly, an important ingredient of successful delegation is accountability: holding the expert accountable for the decisions he has made can in the long run help align the interests of the expert with those of the decisionmaker and improve the value of expertise. A model of delegation with accountability is necessarily dynamic and involves reputational concerns of the expert. We hope to pursue the issue of accountability in future works.

Appendix

PROOF OF PROPOSITION 2.

By the revelation principle, we need only consider direct mechanisms. Each such mechanism is represented by probability of adoption $p(\tilde{y}^a)$ as a function of reported signal $\tilde{y}^a$. The expected cost to expert A when his signal is y^a and he reports $\tilde{y}^a$, is

$$C^a(\tilde{y}^a|y^a) = \eta(y^a)[k_1^a f_n^a(y^a)p(\tilde{y}^a) + k_2^a f_p^a(y^a)(1 - p(\tilde{y}^a)],$$

where $\eta(y^a)$ is the reciprocal of $(1 - \gamma^a)f_n^a(y^a) + \gamma^a f_p^a(y^a)$. Incentive compatibility requires that $C^a(y^a|y^a) \leq C^a(\tilde{y}^a|y^a)$, which can be written as:

$$k_1^a f_n^a(y^a)(p(y^a) - p(\tilde{y}^a)) \leq k_2^a f_p^a(y^a)(p(y^a) - p(\tilde{y}^a)).$$

Similarly, $C^a(\tilde{y}^a|\tilde{y}^a) \leq C^a(y^a|\tilde{y}^a)$ can be written as

$$k_1^a f_n^a(\tilde{y}^a)(p(y^a) - p(\tilde{y}^a)) \geq k_2^a f_p^a(\tilde{y}^a)(p(y^a) - p(\tilde{y}^a)).$$

We can show that $y^a > \tilde{y}^a$ implies that $p(y^a) \geq p(\tilde{y}^a)$: if instead $p(y^a) < p(\tilde{y}^a)$, the two inequalities above imply that $l(y^a) \leq l(\tilde{y}^a)$, contradicting the strict monotonicity of the likelihood ratio. Moreover, if $y^a > \tilde{y}^a$ and $p(y^a) > p(\tilde{y}^a)$, then the two inequalities imply that $y^a \geq \hat{t}^a \geq \tilde{y}^a$, where $\hat{t}^a$ is defined by $l^a(\hat{t}^a) = k^a$.

Having established the first part of the proposition, the optimal mechanism for the decisionmaker can be found by minimizing:

$$k_1^d[(1 - F_n^a(\hat{t}^a))p_1 + F_n^a(\hat{t}^a)p_0] + k_2^d[(1 - F_p^a(\hat{t}^a))(1 - p_1) + F_p^a(\hat{t}^a)(1 - p_0)]$$

subject to $-p_0 \leq 0$, $p_1 - 1 \leq 0$, and $p_0 - p_1 \leq 0$. This is a linear programming program. If we let μ_1, μ_2 and μ_3 be the Lagrange multipliers associated with the three constraints, the first order conditions for p_0 and p_1 are, respectively:

$$[k_1^d F_n^a(\hat{t}^a) - k_2^d F_p^a(\hat{t}^a)] - \mu_1 + \mu_3 = 0;$$
$$[k_1^d(1 - F_n^a(\hat{t}^a)) - k_2^d(1 - F_p^a(\hat{t}^a))] + \mu_2 - \mu_3 = 0.$$

If $k^d < \theta_1^a$, then the terms in square brackets above are both negative, which implies $\mu_2 > 0$ and $\mu_3 > 0$. By complementary slackness, this implies $p_0 = p_1 = 1$. If $k^d > \theta_2^a$, then both terms in square brackets are positive. This implies $\mu_1 > 0$ and $\mu_3 > 0$. Hence $p_0 = p_1 = 0$. Finally, if k^d is between θ_1^a and θ_2^a, then the term in brackets in the first equation is positive while the term in brackets in the second equation is negative. Thus, $\mu_1 > 0$ and $\mu_2 > 0$, which implies $p_0 = 0$ and $p_1 = 1$.

PROOF OF PROPOSITION 5.

By $l^a(t_*^a)L_*^b(t_*^b) = k^a$ and $l^b(t_*^b)L_*^a(t_*^a) = k^b$, we have

$$\begin{aligned}\frac{dt^a}{dk^b} &= \frac{-l^a(L_*^b)'}{(l^a)'L_*^a(l^b)'L_*^b - l^a(L_*^a)'l^b(L_*^b)'},\\ \frac{dt^b}{dk^b} &= \frac{(l^a)'L_*^b}{(l^a)'L_*^a(l^b)'L_*^b - l^a(L_*^a)'l^b(L_*^b)'}.\end{aligned}$$

Since l^e/L_*^e is strictly increasing for each $e = a, b$, we have $(l^e)'L_*^e > l^e(L_*^e)$. The common denominator in the above two expressions is positive. By the definition of θ_*, we have

$$\frac{d\theta_*}{dk^b} = \frac{L_*^a(L_*^b)'((l^a)'L_*^a - l^a(L_*^a)')}{(l^a)'L_*^a(l^b)'L_*^b - l^a(L_*^a)'l^b(L_*^b)'},$$

which is positive because $(l^a)'L_*^a > l^a(L_*^a)'$. By a similar argument, $d\theta_{**}/dk^b > 0$.

PROOF OF PROPOSITION 6.

The first part of Proposition 6 is straightforward. Since $\partial C_*^d/\partial t_*^a$ has the same sign as $k^a - k^d$ and since $dt_*^a/dk^b < 0$, the first term in equation (6) of the text is negative. Since $C_*^d/\partial t_*^b$ has the same sign as $k^b - k^d$ and since $dt_*^b/dk^b > 0$, the second term in equation (6) of the text is non-positive for $k^b \leq k^d$. Thus $dC_*^d/dk^b < 0$ for all $k^b \leq k^d$.

For the second part of the Proposition, we make the assumption that the conditional distributions of Y^a and Y^b are the same. With this assumption we can drop superscripts a and b for distribution functions and likelihood ratio functions. Let

$$\Delta = l'(t_*^a)L_*(t_*^a)l'(t_*^b)L_*(t_*^b) - l(t_*^a)L_*'(t_*^a)l(t_*^b)L_*'(t_*^b).$$

Since l/L_* is strictly increasing, we have $\Delta > 0$. Then, using $dt^a/dk^b = -l(t_*^a)L_*'(t_*^b)/\Delta$, and $dt^b/dk^b = l'(t_*^a)L_*(t_*^b)/\Delta$, we can write dC_*^d/dk^b as

$$\begin{aligned}
&\frac{\partial C_*^d}{\partial t_*^a}\frac{dt^a}{dk^b} + \frac{\partial C_*^d}{\partial t_*^b}\frac{dt^b}{dk^b} \\
=&\frac{k_2^d}{\Delta}[-f_n(t_*^a)F_n(t_*^b)(k^a - k^d)l(t_*^a)L_*'(t_*^b) + f_n(t_*^b)F_n(t_*^a)(k^b - k^d)l'(t_*^a)L_*(t_*^b)] \\
>&\frac{k_2^d}{\Delta}[-f_n(t_*^a)F_n(t_*^b)(k^a - k^d)l(t_*^a)L_*'(t_*^b) \\
&\qquad + f_n(t_*^b)F_n(t_*^a)(k^b - k^d)l(t_*^a)L_*'(t_*^a)L_*(t_*^b)/L_*(t_*^a)].
\end{aligned}$$

The above inequality follows because l/L_* is increasing. Since $L_*' = (l - L_*)f_n/F_n$, we know that dC_*^d/dk^b has the same sign as

$$\begin{aligned}
&-(k^a - k^d)L_*(t_*^a)[l(t_*^b) - L_*(t_*^b)] + (k^b - k^d)L_*(t_*^b)[l(t_*^a) - L_*(t_*^a)] \\
=&-(k^a - k^d)[k^b - L_*(t_*^a)L_*(t_*^b)] + (k^b - k^d)[k^a - L_*(t_*^a)L_*(t_*^b)] \\
=&(k^b - k^a)[k^d - L_*(t_*^a)L_*(t_*^b)].
\end{aligned}$$

Since $k^b > k^a$ and $k^d > \theta_* = L_*(t_*^a)L_*(t_*^b)$, we have $dC_*^d/dk^b > 0$.

Proof of Proposition 8.

In this proof we assume that $k^d < k^a$; the proof is symmetric if $k^d > k^a$. First note that delegation only when $y^d < t_*^d$ is equivalent to delegation only when $y^d \in [\underline{y}^d, t_*^d)$, in terms of the expected cost to the decisionmaker, but the three thresholds $\underline{y}^d$, t_*^d and t_*^a are not best responses to each other. We consider a Cournot tatonnement process that begins with the three thresholds $(\underline{y}^d, t_*^d, t_*^a)$ and converges toward the thresholds (t_1^d, t_2^d, t^a). In each iteration of the Cournot tatonnement, the new thresholds are chosen as best responses to the previous thresholds. The proof proceeds in two steps. In the first step we show that decisionmaker D's two thresholds monotonically increase toward t_1^d and t_2^d respectively, while expert A's threshold monotonically decreases toward t^a. In the second step we show that expected cost to the decisionmaker falls in each iteration of the tatonnement.

At each iteration t, the Cournot tatonnement is defined by $x(t) = h(x(t-1))$, where $x(t) = (z_1^d(t), z_2^d(t), -z^a(t))$ are the three thresholds, and the function $h : \mathcal{R}^3 \to \mathcal{R}^3$ is defined by

$$l^d(z_1^d(t))L_{**}^a(z^a(t-1)) = k^d,$$

$$l^d(z_2^d(t))L_*^a(z^a(t-1)) = k^d,$$

$$l^a(z^a(t))\mathcal{L}^d(z_2^d(t-1), z_1^d(t-1)) = k^a.$$

The monotone likelihood ratio property implies that $h(x)$ is increasing in x (Facts 3 and 4). The initial thresholds are $x(0) = (\underline{y}^d, t_*^d, -t_*^a)$. An induction argument establishes that $x(t)$ increases monotonically. Suppose $x(t) \geq x(t-1)$. Because $h(\cdot)$ is monotonically increasing,

$$x(t+1) = h(x(t)) \geq h(x(t-1)) = x(t).$$

Furthermore, using the definitions of $x(0)$ and h, we can verify $x(1) = h(x(0)) \geq x(0)$, and the induction argument is complete. A bounded and monotone sequence converges to a limit point $\hat{x}$. By the continuity of each member's expected cost in the thresholds, this point must also be an equilibrium point, $\hat{x} = h(\hat{x})$. To see this, note that

$$\tilde{C}^d(z_1^d(t), z_2^d(t), z^a(t-1)) \leq \tilde{C}^d(z_1^d, z_2^d, z^a(t-1))$$

for all z_1^d and z_2^d, because $z_1^d(t)$ and $z_2^d(t)$ are the best response to $z^a(t-1)$. Similarly,

$$\tilde{C}^a(z_1^d(t-1), z_2^d(t-1), z^a(t)) \leq \tilde{C}^a(z_1^d(t-1), z_2^d(t-1), z^a)$$

for all z^a. Since $\tilde{C}^d$ and $\tilde{C}^a$ are continuous in $x(t)$ and $x(t) \to \hat{x}$, these two inequalities imply that $\hat{x} = (t_1^d, t_2^d, -t^a)$.

For the second step of the proof, the expected cost $\tilde{C}^d(z_1^d, z_2^d, z^a)$ to decisionmaker D is

$$k_1^d[1 - F_n^d(z_2^d) + (F_n^d(z_2^d) - F_n^d(z_1^d))(1 - F_n^a(z^a))] + k_2^d[F_p^a(z^a)(F_p^d(z_2^d) - F_p^d(z_1^d)) + F_p^d(z_1^d)].$$

Write the change $\tilde{C}^d(z_1^d(t+1), z_2^d(t+1), z^a(t+1)) - \tilde{C}^d(z_1^d(t), z_2^d(t), z^a(t))$ between two successive iterations as the sum of

$$\tilde{C}^d(z_1^d(t+1), z_2^d(t+1), z^a(t+1)) - \tilde{C}^d(z_1^d(t), z_2^d(t), z^a(t+1)$$

and

$$\tilde{C}^d(z_1^d(t), z_2^d(t), z^a(t+1)) - \tilde{C}^d(z_1^d(t), z_2^d(t), z^a(t)).$$

We claim that (i) $\partial\tilde{C}^d(z_1^d, z_2^d, z^a(t+1))/\partial z_1^d < 0$ and $\partial\tilde{C}^d(z_1^d, z_2^d, z^a(t+1))/\partial z_2^d < 0$ for all for $z_1^d \in [z_1^d(t), z_1^d(t+1)]$ and $z_2^d \in [z_2^d(t), z_2^d(t+1)]$; and (ii) $\partial\tilde{C}^d(z_1^d(t), z_2^d(t), z^a)/\partial z^a > 0$ for $z^a \in [z^a(t+1), z^a(t)]$. Then the conclusion of the proposition follows. To prove (i), note that $\partial\tilde{C}^d(z_1^d, z_2^d, z^a(t+1))/\partial z_1^d$ has the same sign as $l^d(z_1^d)L_{**}^a(z^a(t+1)) - k^d$. Since $z_1^d \leq z_1^d(t+2)$ and $l^d(z_1^d(t+2))L_{**}^a(z^a(t+1)) = k^d$, $\partial\tilde{C}^d(z_1^d, z_2^d, z^a(t+1))/\partial z_1^d < 0$. Similarly, $\partial\tilde{C}^d(z_1^d, z_2^d, z^a(t+1))/\partial z_2^d$ has the same sign as $l^d(z_2^d)L_*^a(z^a(t+1)) - k^d$. Since $z_2^d \leq z_2^d(t+2)$ and $l^d(z_2^d(t+2))L_*^a(z^a(t+1)) = k^d$, $\partial\tilde{C}^d(z_1^d, z_2^d, z^a(t+1))/\partial z_2^d < 0$. To prove (ii), note $\partial\tilde{C}^d(z_1^d(t), z_2^d(t), z^a)/\partial z^a$ has the same sign as $l^a(z^a)\mathcal{L}^d(z_2^d(t), z_1^d(t)) - k^d$. Since $k^d < k^a$, $z^a \geq z^a(t+1)$, and $l^a(z^a(t+1))\mathcal{L}^d(z_2^d(t), z_1^d(t)) = k^a$, we immediately have $\partial\tilde{C}^d(z_1^d(t), z_2^d(t), z^a)/\partial z^a > 0$.

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