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Delegation to a potentially uninformed agent [*]

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Abstract

We consider a delegation problem with a biased and potentially uninformed agent when the principal cannot use monetary payments. If the bias between the principal and the agent is large then the optimal delegation set is an interval. When the bias is small or medium the optimal delegation set is no longer connected. It can be one of two types: 1) with an interval and low option, 2) with two intervals. In all cases the agent has less discretion. However, in the case of medium bias the principal delegates in a wider range than in the case of an informed agent.

Key words: *Information, bias, non-informed agent, delegation set.*

JEL Classification: D82, D86.

Résumé

Nous considérons un problème de délégation avec un agent potentiellement mal informé lorsque le principal ne peut pas utiliser les paiements monétaires. Si l'écart entre le principal et l'agent est grande l'ensemble optimal de délégation est un intervalle. Lorsque le biais est petit ou moyenne l'ensemble optimal de délégation n'est plus connecté. Il peut s'agir de deux types: 1) avec un intervalle et l'option faible, 2) avec deux intervalles. Dans tous les cas, l'agent à moins de discrétion. Toutefois, dans le cas de milieu biaiser les délégués principaux dans une gamme plus large que dans le cas d'un agent informé.

Mots clés : *Informations, de biais, agent non informés, ensemble de la délégation.*

Classification JEL : D82, D86.

Introduction

In many economics situations an uninformed principal delegates decision-making to an informed agent. A manager in a firm has superior to a CEO information about investment projects. If the manager and the CEO have identical preferences in which project to invest then it would be in the CEO interests do not restrict the agent's discretion. However the manager may be biased; he wants to invest in too risky, from the CEO's point of view, projects. Therefore the CEO constrains the manager's discretion by solving optimally the trade-off between the use of information and the manager's bias. In reality the manager not always has the superior to the CEO information. For example a junior manager just has started his career and does not have experience in collecting information. A manager may be too busy with other projects to acquire the relevant information. Finally, the agent observes the realization of the pilot project which may fail to provide information. In all such cases there is a probability that the agent will have, at the moment of taking the decision, no informational advantage before the principal.

This paper studies a delegation problem when the biased agent with some positive probability is uninformed and the principal cannot use monetary payments. The principal selects a set of actions from which the agent is required to choose - a delegation set. In choosing the limits of the delegation set the principal faces a trade-off between the use of the agent's information and control over decisions. If the bias between the principal and the agent is sufficiently large, the optimal delegation set is an interval. When the bias is small or medium the optimal delegation set is no longer connected. For small biases it consists of two intervals. For medium biases it consists of an interval and low option. If the agent is uninformed he wants to choose the policy equal to the expected value of the state of nature. This policy is too low from the principal's point of view. Thus the principal introduces a discontinuity in the delegation set. Generally, the principal exerts more control over the potentially uninformed agent compared to the informed agent; there are fewer choices available for the agent. The delegation problem was first analyzed by Holmström (1977). Assuming interval delegation he has shown that the agent will be given more freedom when he gets more informed (the Uncertainty Principle) or when the agent's preferences come closer to the principal's (the Ally Principle). We show that these Principles hold when the probability of being informed (or the bias) is sufficiently large or small. However in the case of medium probabilities (or biases) the range of the delegation set is larger than in the case of the informed agent. The principal distorts the delegation set downwards in order to benefit from the information in the low-end of the distribution.

The constrained delegation framework has recently become popular to analyze a variety of economic situations: the limits placed on Central Bank monetary or exchange rate policy, price limits in regulation, the House regulations on policies that a delegated committee may choose, tariff levels etc. This literature was pioneered by Holmström (1977) who proves under general conditions that there exists an optimal delegation set. Holmström (1984) and Armstrong (1994) assume that the optimal delegation set is an interval. Following this tradition most of the literature focused on interval delegation with an informed agent. Melumad and Shibano (1991), Martimort and Semenov (2006), Alonso and Matouschek (2008), Kovac and Mylovanov (2009) and Amador and Bagwell (2011) give different sufficient conditions under which the optimal delegation set is an interval. Frankel (2012) shows that in the case of multiple decisions a half-space analog of an interval delegation set is optimal in the case of a normal distribution of types and quadratic payoffs.

Melumad and Shibano (1991) presented a condition on payoff functions of the principal and the agent in order to have a non-interval optimal delegation set. The ideal decisions of the principal should be higher than the ideal decisions for the agent for some states and lower for others. Martimort and Semenov (2006) and Kovac and Mylovanov (2009) pointed out conditions on distributions of types when the optimal delegation set can be non-interval. This paper shows that with conventional payoffs and distributions, non-connectedness of the optimal delegation set may arise if the agent may be uninformed. Szalay (2005) considers the case when the *non-biased* agent may choose the probability of being informed. The optimal delegation set in this case exhibits a gap in the middle of the distribution. This gap is introduced in order to improve incentives for information collection. We show, using the classification of the optimal delegation sets, that inducing the agent to collect information leads to more delegation to the agent than in the case of an exogenous probability of being informed.

In the literature on signaling games Austen-Smith (1994) established that the possibility of an uninformed sender makes information transmission possible for a wider range of conflicts between the receiver and the sender compare to the cases when the sender is informed. The reason for this arising is different from ours; the low - type sender pools with the uninformed sender. This leads to a more favorable action for the low-type sender which makes it is easier for high - type sender to separate himself than in the case when the receiver is sure that the sender is informed. Lewis and Sappington (1993) consider the optimal contract with the possibility of ignorance when the principal may use transfers to elicit information. The payoff of the principal does not depend on the information parameter (private values). In this framework there is always a discontinuity in the optimal output. The optimal contract exhibits pooling and when costs are high the output is lower than in the standard second best.

The Model

A principal (she) delegates the making of a decision $d \in \mathbb{R}$ to an agent (he). The single - peaked payoffs of the principal and the agent are $V_P(d,\theta)$ and $V_A(d,\theta)$ respectively, where the state of the world $\theta \in \Theta = \left[\underline{\theta}, \overline{\theta}\right]$ is drawn from the distribution with non-atomic, continuous density function $f(\theta)$ and cumulative density function $F(\theta)$. The principal does not observe θ. The game is as follows:

1. The principal chooses a closed delegation set $D \subset \mathbb{R}$.
2. With probability $1-p$ the agent learns the state θ, with probability p the agent remains uninformed. The probability p is common knowledge, but the principal is unaware if the agent is informed.
3. The agent chooses $d \in D$.

The delegation set $D = \{D_{\text{inf}}, d_0\}$, where we denote by $d_0 \in D$ the choice of the uninformed agent and the set of choices of the informed agent by D_{inf}. If the agent learns that the state is θ then his payoff is $V_A(d(\theta),\theta)$, where $d(\theta) = \arg\max_{d \in D_{\text{inf}}} V_A(d,\theta)$. The expected payoff of the uninformed agent is $\int_\Theta V_A(d_0,\theta)\, dF(\theta)$.

The choice of the agent maximizes his payoff in the delegation set. If the agent is informed that the state is $\theta \in \Theta$ then

$$V_A(d(\theta), \theta) \geq V_A(d(\theta'), \theta) \text{ for all } \theta, \theta' \in \Theta. \tag{1}$$

When the agent does not observe the state, he prefers d_0 to any other outcome $d(\theta') \in D_{\text{inf}}$ if

$$\int_\Theta V_A(d_0, \theta)\, dF(\theta) \geq \int_\Theta V_A(d(\theta'), \theta)\, dF(\theta) \text{ for all } \theta, \theta' \in \Theta. \tag{2}$$

Finally, if the agent observes the state θ, he prefers $d(\theta)$ to d_0 if

$$V_A(d(\theta), \theta) \geq V_A(d_0, \theta). \tag{3}$$

A delegation set D is optimal if it maximizes the principal's expected payoff among all closed sets. The principal's expected payoff is

$$V(D) = p \int_\Theta V_P(d_0, \theta)\, dF(\theta) + (1-p) \int_\Theta V_P(d(\theta), \theta)\, dF(\theta).$$

We denote the first part of the principal's payoff as $V_0(D)$ and the second part as $V_{\text{inf}}(D)$ so that $V(D) = pV_0(D) + (1-p)V_{\text{inf}}(D)$. In order to simplify calculations and obtain the closed form delegation sets we focus on quadratic specifications of payoffs,

$$V_A(d, \theta) = -\frac{1}{2}(d-\theta)^2 \text{ and } V_P(d, \theta) = -\frac{1}{2}(d-\theta-b)^2,$$

where the parameter $b \geq 0$ is the bias between the principal and the agent. We assume that the bias b is common knowledge.

The delegation sets have the form $D = \left\{ \left(\overset{n}{\underset{i=1}{\cup}} D_i \right), d_0 \right\}$, where $D_i = \left[\underline{d}_i, \overline{d}_i \right], i = 1, ..., n$ are closed intervals, $\underline{d}_i \leq \overline{d}_i < \underline{d}_{i+1} \leq \overline{d}_{i+1}$ for all $i = 1, ..., n-1$. If $n = 1$ we have interval delegation set. The choice of the informed agent θ is the following: if $\theta \in D_i = \left[\underline{d}_i, \overline{d}_i \right]$ then $d(\theta) = \theta$. If $\theta \in \left(\overline{d}_i, \frac{\overline{d}_i + \underline{d}_{i+1}}{2} \right)$ then $d(\theta) = \overline{d}_i$. If $\theta \in \left(\frac{\overline{d}_i + \underline{d}_{i+1}}{2}, \underline{d}_{i+1} \right)$ then $d(\theta) = \underline{d}_{i+1}$. Finally, if $\theta = \frac{\overline{d}_i + \underline{d}_{i+1}}{2}$ then $d(\theta) \in \left\{ \overline{d}_i, \underline{d}_{i+1} \right\}$. The expected payoff of the principal is

$$V(D) = pV_0(D) + (1-p) V_{\text{inf}}(D) = -\frac{p}{2} \int_{\underline{\theta}}^{\overline{\theta}} (d_0 - \theta - b)^2\, dF(\theta) -$$

$$\frac{1-p}{2} \left\{ \int_{\underline{\theta}}^{\underline{d}_1} (\underline{d}_1 - \theta - b)^2\, dF(\theta) + \sum_{i=1}^n \int_{\underline{d}_i}^{\overline{d}_i} b^2 dF(\theta) + \sum_{i=1}^n \int_{\overline{d}_i}^{\frac{\overline{d}_i + \underline{d}_{i+1}}{2}} (\underline{d}_i - \theta - b)^2\, dF(\theta) + \right.$$

$$\left. + \sum_{i=1}^n \int_{\frac{\overline{d}_i + \underline{d}_{i+1}}{2}}^{\underline{d}_{i+1}} \left(\underline{d}_{i+1} - \theta - b \right)^2 dF(\theta) + \int_{d_n}^{\overline{\theta}} \left(\overline{d}_n - \theta - b \right)^2 dF(\theta) \right\}.$$

We assume that the distribution of states satisfies the following

Assumption 1 *The function $F(\theta)$ is log-concave and for all $\theta \in \Theta$ the function $f(\theta) - bf'(\theta)$ is positive for all $\theta \in \Theta$ and decreasing in θ.*

Examples of distributions satisfying this assumption are uniform distributions and exponential distributions. For future reference, note that if $F(\theta)$ is log-concave then both $\frac{F(\theta)}{f(\theta)}$ and $\frac{\int_{\underline{\theta}}^{\theta} F(\theta)d\theta}{F(\theta)}$ are strictly increasing functions of θ (see for example Prékopa, 1973). Martimort and Semenov (2006) show that if the agent is always informed, $F(\theta)$ is log-concave and $f(\theta) - bf'(\theta) \geq 0$ for all θ then the optimal delegation set is an interval.

Results

The delegation is valuable if the principal benefits from delegating decision - making to the agent instead of making the decision by herself. Our first result establishes the types of the optimal delegation sets when the delegation is valuable. Define $b_{\max} = \overline{\theta} - E(\theta)$.

Proposition 1 *If $p \in [0, 1)$ and $b \in [0, b_{\max})$, then the delegation is valuable and the optimal delegation set has one of the following types:*

1. Interval delegation: $D = \left\{ \left[d_0, \overline{\theta}\right], d_0 \right\}$, where $d_0 \leq E(\theta) + b$;

2. Interval and point delegation: $D = \left\{ \{d_1\} \cup \left[d_0, \overline{\theta}\right], d_0 \right\}$, where $E(\theta) \leq d_0 < E(\theta) + b$ and $d_1 + d_0 = 2E(\theta)$;

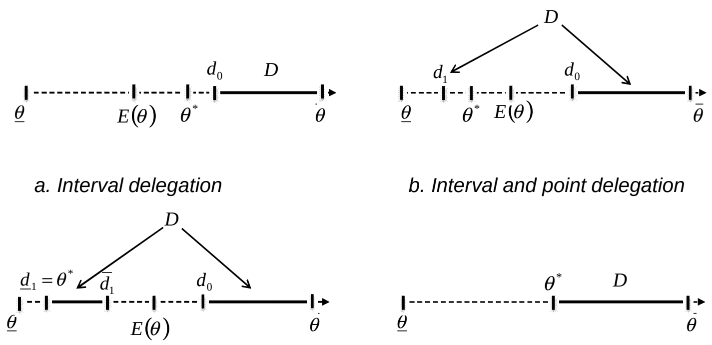
3. Two - intervals delegation: $D = \left\{ \left[\underline{d}_1, \overline{d}_1\right] \cup \left[d_0, \overline{\theta}\right], d_0 \right\}$, where $\overline{d}_1 \leq E(\theta) \leq d_0 < E(\theta) + b$ and $\overline{d}_1 + d_0 = 2E(\theta)$.

The delegation sets are presented in Figure 1 a-c. The interesting feature of types 2 and 3 delegation (presented in Figure 1 b and c) is that they are not connected. Note also that in case 2 d_1 and d_0 are equidistant from $E(\theta)$ and in case 3 $\overline{d}_1$ and d_0 are equidistant from $E(\theta)$. The principal wants to limit the choice of the uninformed agent whose ideal policy is $E(\theta)$. This policy is too low for the principal who prefers $E(\theta) + b$ when the agent is uninformed. Hence, she introduces a gap in the delegation set in order to control the uninformed agent.

These delegation sets are common in real-life situations. Graduate committee at the university constrains the actions of departments when hiring new professors or admitting new graduate students. For example the department may accept a graduate candidate only if his/her average is above a predetermined average GPA. Judges must choose between acquitting or sentencing: "If an accused person is found not guilty, they are acquitted of the charge and are free to go. If an accused person pleads guilty or is found guilty at trial, the judge must choose from a range of sentences set by law and determine an appropriate sentence".[1]

[1] Criminal Code of Canada: A Crime Victim's Guide to the Criminal Justice System: http://www.justice.gc.ca/eng/pi/pcvi-cpcv/guide/seci.html.

Figure 1. Optimal delegation sets



a. Interval delegation

b. Interval and point delegation

c. Two intervals delegation

d. Delegation with informed agent

Proof: If the principal chooses the decision by herself then the decision is $E(\theta)+b$. Delegation is valuable when $V(E(\theta)+b) = -\frac{1}{2}\int_{\underline{\theta}}^{\overline{\theta}}(E(\theta)-\theta)^2\,dF(\theta)$ is less than the principal's payoff achieved by delegation. Consider the delegation set $\widetilde{D} = \{[E(\theta)+b,\overline{\theta}], E(\theta)+b\}$. We have

$$V(\widetilde{D}) - \max_d V(\{d\}) = \frac{1-p}{2}\int_{E(\theta)+b}^{\overline{\theta}}(E(\theta)-\theta-b)(E(\theta)-\theta+b)\,dF(\theta) > 0.$$

Hence, delegation is valuable. We will prove the Proposition 1 in a few Lemmas. Denote by $d(\theta^-) = \lim_{\theta'\to\theta-0} d(\theta')$ and by $d(\theta^+) = \lim_{\theta'\to\theta+0} d(\theta')$.

Lemma 1 $d_0 \in \{d^-(E(\theta)), d^+(E(\theta))\}$.

Proof. Re-write (2) as $(d(\theta')-d_0)(d(\theta')+d_0-2E(\theta)) \geq 0$ and (3) as $(d(\theta')-d_0)(d(\theta')+d_0-2\theta') \leq 0$. From these inequalities we obtain $(d(\theta')-d_0)(\theta'-E(\theta)) \geq 0$. Thus, for any $\varepsilon > 0$ we have $d(E(\theta)+\varepsilon) \geq d_0 \geq d(E(\theta)-\varepsilon)$. Taking the limit, we get $d_0 \in \{d^-(E(\theta)), d^+(E(\theta))\}$. ∎

From this Lemma if there exists i such that $E(\theta) \in D_i$ then $d_0 = d(E(\theta))$. If for some i we have $E(\theta) \in (\overline{d}_i, \underline{d}_{i+1})$ then d_0 is either $\overline{d}_i$ or $\underline{d}_{i+1}$.

Definition 1 *Consider a set* $D_{\inf} = \bigcup_{i=1}^{n} D_i$. *We fix* $k \leq n-1$ *and define* $(\varepsilon, k)-$ *transformation of* D *as* $D_{\inf}(\varepsilon) = \bigcup_{i=1}^{n} D'_i$ *such that* $D'_i = D_i$ *for all* $i \neq k, k+1$ *and* $D'_k = [\underline{d}_k, \overline{d}_k + \varepsilon]$, $D'_{k+1} = [\underline{d}_{k+1} - \varepsilon, \overline{d}_{k+1}]$, *where* $\varepsilon > 0$ *is such that* $\overline{d}_k + \varepsilon < \underline{d}_{k+1} - \varepsilon$.

The derivative of $V_{\inf}(D_{\inf}(\varepsilon))$ with respect to ε evaluated at $\varepsilon = 0$ is greater than zero if

$$b(2F(\theta') - F(\theta'-\Delta) - F(\theta'+\Delta)) - \int_{\theta'-\Delta}^{\theta'} F(\theta)d\theta + \int_{\theta'}^{\theta'+\Delta} F(\theta)d\theta \geq 0. \quad (4)$$

The Assumption 1 provides a sufficient condition for (4). Indeed, consider the function

$$\pi(t) = b(2F(\theta') - F(\theta' - t) - F(\theta' + t)) - \int_{\theta'-t}^{\theta'} F(\theta)d\theta + \int_{\theta'}^{\theta'+t} F(\theta)d\theta,$$

where $t \in [0, \Delta]$. We have $\pi(0) = 0$ and $\pi'(t) = b(f(\theta' - t) + f(\theta' + t)) - F(\theta' - t) + F(\theta' + t)$. Then $\pi''(0) = 0$ and $\pi''(t) > 0$ for all $t > 0$.

Lemma 2 *The optimal delegation set $D = \{D_{\inf}, d_0\}$ has at most two disjoint intervals.*

Proof. Assume first that there exist i such that $E(\theta) \in D_i$ then $d_0 = d(E(\theta))$. If for $k + 1 \leq i$ there are two disjoint sets $D_k = [\underline{d}_k, \overline{d}_k]$ and $D_{k+1} = [\underline{d}_{k+1}, \overline{d}_{k+1}]$ then consider $(\varepsilon, k)-$ transformation $D_{\inf}(\varepsilon)$ of $D_{\inf}$. With such a transformation d_0 is still the choice of the uninformed agent. Consider $D(\varepsilon) = \{D_{\inf}(\varepsilon), d_0\}$ for small $\varepsilon > 0$. We have $V_0(D) = V_0(D(\varepsilon))$ and $V(D(\varepsilon)) > V(D)$ which contradicts the optimality of D. The case $k + 1 > i$ is similar. Hence in this case the set $D_{\inf}$ is an interval. By the same token if for some i we have $E(\theta) \in (\overline{d}_i, \underline{d}_{i+1})$ then we repeat the same steps but for $k + 1 < i$ and $k + 1 > i$. Thus the set $D = \{D_{\inf}, d_0\}$ consists of two disjoint intervals. ■

In order to compare the delegations sets in Proposition 1 with the delegation set when the agent is always informed ($p = 0$) we reference the well-known result (see Martimort and Semenov, 2006).

Lemma 3 *If $p = 0$ then the optimal delegation set is an interval $D^* = \{[\theta^*, \overline{\theta}], \theta^*\}$, where θ^* is defined by*

$$\theta^* = b + E(\theta \mid \theta \leq \theta^*). \tag{5}$$

Proof. When $p = 0$ the agent is always informed and by Lemma 2 $D = \{[\theta_1, \overline{\theta}], \theta_1\}$. The principal's expected profit is

$$V(D) = V_{\inf}(D) = -\frac{1}{2}\int_{\underline{\theta}}^{\theta_1} (\theta_1 - \theta - b)^2 dF(\theta) - \frac{1}{2}\int_{\theta_1}^{\overline{\theta}} b^2 dF(\theta).$$

The first-order condition for θ_1 leads to (5). ■

The optimal delegation set with the informed agent is depicted in Figure 1 d. Lemma 1 shows that $d_0 \in \{d^-(E(\theta)), d^+(E(\theta))\}$. We show that $d_0 = d^+(E(\theta)$.

Lemma 4 $d_0 = d^+(E(\theta) \geq \theta^*$.

Proof. a) Let $D = \{D_{\inf}, d_0\}$ be the optimal delegation set. We prove first that $d_0 \geq \theta^*$. Assume instead that $d_0 < \theta^*$. Consider the optimal delegation set D^* defined in Lemma 3. Because of the optimality of D we have $pV_0(D) + (1-p)V_{\inf}(D) \geq pV_0(D^*) + (1-p)V_{\inf}(D^*)$. By Lemma 3 we have $V_{\inf}(D^*) \geq V_{\inf}(D)$. Hence $V_0(D^*) \leq V_0(D)$. This leads to $(d_0 - \theta^*)(d_0 + \theta^* - 2E(\theta) - 2b) \leq 0$. If $d_0 < \theta^*$ then $d_0 + \theta^* \geq 2E(\theta) + 2b$ or $\theta^* > b + E(\theta)$, which contradicts (5). Hence we have proven that $d_0 \geq \theta^*$.

b) We prove that $d_0 = d^+(E(\theta)$. Assume to the contrary that $d_0 = d^-(E(\theta) < d^+(E(\theta)$ and $D_{\inf} = [d_1, d_0] \cup [d^+(E(\theta), d_2]$. Then we have $E(\theta) \geq d_0 \geq \theta^*$. We apply $(\varepsilon, 1)-$ transformation to the set $D_{\inf}$ and obtain $D_{\inf}(\varepsilon)$. Consider the delegation set $\widetilde{D} = \{D_{\inf}(\varepsilon), d_0 + \varepsilon\}$. We have $V_{\inf}(\widetilde{D}) > V_{\inf}(D)$ and $V_0(\widetilde{D}) > V_0(D)$. Contradiction. ■

From Lemma 2 and Lemma 4 it follows that the optimal contract belongs to one of types 1-3 of Proposition 1. Note first that for types 2 and 3 $\frac{d^+(E(\theta))+d^-(E(\theta))}{2} \leq E(\theta)$. Indeed, if $\frac{d^+(E(\theta))+d^-(E(\theta))}{2} > E(\theta)$ then $d_0 < E(\theta)$ and $d_0 \geq \theta^*$. As in Lemma 4 *b)* we can consider the set $\widetilde{D}$ and obtain a strict improvement. Thus, $\frac{d^+(E(\theta))+d^-(E(\theta))}{2} \leq E(\theta)$.

Lemma 5 *If $p < 1$ then $d_0 < E(\theta) + b$.*

Proof. See Appendix. ■

Using Lemma 2 we consider delegation sets with only two disjoint intervals.

Definition 2 *Consider a set $D = \{[\theta_1, \theta' - \Delta] \cup [\theta' + \Delta, \theta_2], \theta' + \Delta\}$. We define $\delta-$ transformation $D(\delta) = \left\{[\underline{\theta}, \theta' - \Delta + \delta] \cup \left[\theta' + \Delta + \delta, \overline{\theta}\right], \theta' + \Delta + \delta\right\}$.*

The derivative of $V_{\inf}(D(\delta))$ with respect to δ evaluated at $\delta = 0$ is positive when

$$f(\theta' + t) - bf'(\theta' + t) \leq f(\theta' - t) - bf'(\theta' - t) \text{ for all } t \in [0, \Delta].$$

This condition is satisfied by Assumption 1.

We prove the Proposition 1. Using Lemma 2 there are two possibilities; either the optimal delegation set is an interval $D = \{[\theta_1, \theta_2], \theta_1\}$, or it has the form $D = \{[\theta_1, \theta' - \Delta] \cup [\theta' + \Delta, \theta_2], \theta' + \Delta\}$. Note that $\theta_2 = \overline{\theta}$. Indeed, if $\theta_2 < \overline{\theta}$, then the delegation sets $D = \{\left[\theta_1, \overline{\theta}\right], E(\theta)\}$ and $D = \{[\theta_1, \theta' - \Delta] \cup \left[\theta' + \Delta, \overline{\theta}\right], \theta' + \Delta\}$ strictly dominate respective delegation sets.

If the optimal delegation set is an interval then it is of the type 1. Assume that $D = \{[\theta_1, \theta' - \Delta] \cup \left[\theta' + \Delta, \overline{\theta}\right], \theta' + \Delta\}$ and $\frac{d^+(E(\theta))+d^-(E(\theta))}{2} \neq E(\theta)$. Because $\theta' + \Delta < E(\theta) + b$ by Lemma 5 there exist $\delta > 0$ such that $\theta' + \Delta + \delta \leq E(\theta) + b$. Then the $\delta-$ transformation $D(\delta) = \{[\underline{\theta}, \theta' - \Delta + \delta] \cup \left[\theta' + \Delta + \delta, \overline{\theta}\right], \theta' + \Delta + \delta\}$ improves both V_0 and $V_{\inf}$. Contradiction. Therefore in both cases 2 and 3 the intervals of delegation are equidistant from $E(\theta)$. ■

Remark 1 *Note that when the intervals of delegation are equidistant from $E(\theta)$ we cannot improve by introducing the $\delta-$ transformation because in this case d_0 changes from $d^+(E(\theta))$ to $d^-(E(\theta)) + \delta$ which is further away from $E(\theta) + b$ and, therefore, the component V_0 sharply decreases.*

Following Proposition 1 we write the principal's payoffs in each case as:

$$V_1 = pV_0 - \frac{1-p}{2}\left[\int_{\underline{\theta}}^{d_0}(d_0 - \theta - b)^2 dF(\theta) + \int_{d_0}^{\overline{\theta}} b^2 dF(\theta)\right],$$

$$V_2 = pV_0 - \frac{1-p}{2}\left[\int_{\underline{\theta}}^{E(\theta)}(2E(\theta) - d_0 - \theta - b)^2 dF(\theta) + \int_{E(\theta)}^{d_0}(d_0 - \theta - b)^2 dF(\theta) + \int_{d_0}^{\overline{\theta}} b^2 dF(\theta)\right],$$

$$V_3 = pV_0 - \frac{1-p}{2}\left[\int\limits_{\underline{\theta}}^{d_1}(d_1-\theta-b)^2 dF(\theta) + \int\limits_{\widehat{\theta}}^{2E(\theta)-d_0} b^2 dF(\theta) + \right.$$

$$\left. \int\limits_{2E(\theta)-d_0}^{E(\theta)} (2E(\theta)-d_0-\theta-b)^2 dF(\theta) + \int\limits_{E(\theta)}^{d_0}(d_0-\theta-b)^2 dF(\theta) + \int\limits_{d_0}^{\overline{\theta}} b^2 dF(\theta)\right].$$

The parameters of delegation sets in Proposition 1 satisfy the following inequalities:

Corollary 1 *If* $p \in (0,1)$ *then for corresponding types in Proposition 1 we have:*

1. $d_0 > \theta^*$;

2. $d_1 \leq \theta^* < d_0$;

3. $d_1 = \theta^*$.

For the type 1 the agent has less discretion compared to the case when he is always informed. This is because in this case information is less important for the principal. Thus she wants to exert more control over decisions. The principal moves the boundary of delegation closer to the optimal policy of the uninformed agent, $E(\theta)+b$. This is generally true for all types of delegation sets. For type 2, the delegation set consists of the set $\left[d_0, \overline{\theta}\right]$ and the option $d_1 \leq \theta^*$. The principal wants to use information below d_0, but she cannot delegate to medium types because she wants to limit the choice of the uninformed agent. For the delegation set of type 3, the principal makes use of information held by the upper and lower tails of the distribution still exerting control over the choice of the uninformed agent.

Comparative statics with respect to the bias: We fix the probability p and consider the type i delegation set D in Proposition 1. This delegation set is uniquely determined by the outcome d_0. Let $V_i(d_0, b)$ is the corresponding expected payoff of the principal and $d_0^{(i)}(b)$ is the maximizer of $V_i(d_0, b) : d_0^{(i)}(b) = \arg\max_{d_0} V_i(d_0, b)$. Define b_1 as the solution of

$$2E(\theta) - d_0^{(2)}(b_1) = \theta^*$$

and b_2^* is defined by

$$b_2^* = \frac{1}{F(E(\theta))}\int_{\underline{\theta}}^{E(\theta)} F(\theta)\, d\theta. \tag{6}$$

The bias b_2^* is such that the delegation set for the informed agent is $\left[E(\theta), \overline{\theta}\right]$. We have the following:

Proposition 2 *If* $p \in (0,1)$ *then* $\frac{dd_0^{(i)}(b)}{db} > 0$ *for* $i = 1,2,3$ *and there exist* b_1 *and* $b_2, b_2 > b_2^* > b_1$ *such that:*

1) (Interval delegation) if $b \in [b_2, b_{\max}]$ *then the optimal delegation set is of type 1;*

2) (Interval and point delegation) if $b \in [b_1, b_2)$ *then the optimal delegation set is of type 2;*

3) (Two - intervals delegation) if $b \in [0, b_1)$ *then the optimal delegation set is of type 3.*

If the bias b is large, then the optimal delegation set with the uninformed agent is the interval $D = \left[d_0, \overline{\theta}\right]$. For parameters $\theta < d_0$, the preferred decision of the agent is θ which is smaller than the principal's preferred decision $E(\theta \mid \theta \leq d_0) + b$. Hence, the principal sets a low limit. This limit is greater, however, than the corresponding limit for the informed agent case θ^*. If the principal faces only the uninformed agent, she wants to implement $E(\theta) + b$. When there is a non-zero probability of the agent being informed, the principal controls the uninformed agent by moving the limit of delegation towards $E(\theta) + b$.

For medium and small levels of bias, the principal values information in the low end of the distribution because the preferred decisions of the agent may be very close to the conditional principal's preferred decision of $E(\theta \mid \theta \leq d_0) + b$. Thus, delegating only to the upper end may be very costly for the principal and she gives the choice d_1 for the low end of the distribution. The option d_1 is set optimally below θ^*. If $d_1 > \theta^*$ then the principal can do better by adding the extra interval of delegation $[\theta^*, d_1]$. This happens when the bias is small. Note that in this case the principal delegates in the same range as for the informed agent problem. By excluding intermediate choices she constrains the choice of the uninformed agent.

Example 1 *Consider uniformly distributed types $\theta \sim Uni\,[0,1]$. In this case the optimal delegation set with the informed agent is $D^* = \left[2b, \overline{\theta}\right]$ and delegation is valuable when $b < \frac{1}{2}$. All three delegation sets types are determined by corresponding d_0. We have for $b \in \left[\frac{1}{4}, \frac{1}{2}\right]$ the type 1 is optimal, for $b \in \left[\frac{1}{6}, \frac{1}{4}\right)$ the type 2 is optimal and for $b < \frac{1}{6}$ the type 3 is optimal. Corresponding d_0 are:*

$$d_0^{(1)}(b) = b - \frac{p}{1-p} + \sqrt[2]{b^2 + \frac{p}{(1-p)^2}},\ d_0^{(2)}(b) = b - \frac{p}{1-p} + \sqrt[2]{b^2 + \frac{p}{(1-p)^2} + \frac{1}{2} - 2b}$$

$$\text{and } d_0^{(3)}(b) = 1 - \frac{1 - \sqrt[2]{p\,(4b + p - 4bp)}}{2\,(1-p)}.$$

Note that if $b \to 0$ then $d_0^{(3)}(b) \to \frac{1}{2} = E(\theta)$.

Discussion

The structure of the optimal delegation sets detailed in Propositions 1 and 2 allows us to consider the effect of changes in probabilities on the optimal delegation set and the effect of allowing the agent to choose the probability of being informed.

More informed agent: the Uncertainty Principle

Holmström (1977) has shown that the agent will be given more freedom when he is more informed. He used the normally distributed state of the world, $\theta \sim N(\mu, \sigma^2)$ and considers the comparative statics of interval delegation when σ^2 decreases. Complimentary we show that the Uncertainty Principle holds in our setting when the probability $1-p$ of the agent being informed increases. We fix the bias b and consider the optimal delegation set $D\,(p)$ as a function of p. By Proposition 1 the optimal delegation set of type i is uniquely determined by the outcome d_0. Denote by $V_i\,(d_0, p)$ the expected payoff of the principal and $d_0^{(i)}(p)$ as the maximizer of $V_i(d_0, p) : d_0^{(i)}(p) = \arg\max_{d_0} V_i(d_0, p)$. The first order conditions of $V_i(d_0, p)$ for p $(i = 1, 2, 3)$ determine $d_0(p)$ as monotonic in p functions.

Consider the type 1 optimal delegation set. The optimal d_0 is given by

$$d_0(p) = E(\theta \mid \theta \leq d_0) + b + \frac{p}{1-p}\frac{E(\theta) + b - d_0}{F(d_0)}.$$

Because $\frac{E(\theta)+b-d_0}{F(d_0)} > 0$ we have $d_0'(p) > 0$. Intuitively, when the agent is more informed, then the informed component of principal's payoff $V_{\inf}$ has relatively more weight than the uninformed component V_0. The principal wants to delegate more to the agent in order to benefit from information and she exerts less control. We have the following

Proposition 3 *a)* $\frac{dd_0^{(i)}(p)}{dp} > 0$ *for* $i = 1, 2, 3$,

b) Both the principal and the agent benefit when p *decreases.*

Note here that if the type of the optimal delegation set is 1 or 3 then for the probabilities $p_1 < p_2$ of the agent being uninformed we have strict inclusion $D(p_1) \supsetneq D(p_2)$, where $D(p_k), k = 1, 2$ are the optimal delegation sets.

Choice of probability

Szalay (2005) in the case of a non-biased agent shows that it is optimal for the principal to exclude the interval in the middle of the range of distribution when the agent can choose the probability of being informed. Note that Szalay (2005) allows the principal to use transfers in order to express the payoff of the principal as the welfare maximizing problem. The transfers, however, do not serve as incentive device because the agent is infinitely risk-averse to income risk.

Consider the possibility that the *biased* agent can choose the probability of obtaining information. For example, the agent can participate in the pilot project and choose the effort level that increases the probability of success. On the one hand from Proposition 3 the agent benefits from the increased probability of being informed. On the other hand the effort e imposes costs for the agent $\nu(e)$, where $\nu(\cdot)$ satisfies the Inada conditions.

Timing is as follows: the principal chooses a closed delegation set $\widetilde{D} \subset \mathbb{R}$. Then the agent chooses the effort level $e \geq 0$. The agent is informed about the state with probability $1 - p + e$ and uninformed with probability $p - e$. The effort choice is not observable to the principal. Finally, the agent chooses $d \in \widetilde{D}$.

Define $\widetilde{D} = \{D_{\inf}, d_o\}$, where $D_{\inf} = \{d(\theta)\}_{\theta \in \Theta}$ is the closed set of choices for the informed agent and d_0 is the choice of the uninformed agent. Consider the following program:

$$\max_{\widetilde{D}} (p - e)V_0\left(\widetilde{D}\right) + (1 - p + e)V_{\inf}\left(\widetilde{D}\right)$$

such that (1), (2), (3) and

$$e \in \arg\max_{\widetilde{e}} (p - \widetilde{e}) \int_\Theta V_A(d_0, \theta)\, dF(\theta) + (1 - p + \widetilde{e}) \int_\Theta V_A(d(\theta), \theta)\, dF(\theta) - \nu(\widetilde{e}). \quad (7)$$

We assume that the optimal delegation set exists. Because the optimal delegation set satisfies the conditions (1), (2), (3) and Proposition 1 does not depend on the probability p, the optimal delegation set has the same structure as in Proposition 1. The condition (7) is the incentive compatibility condition for the agent. By Inada conditions it is equivalent to

$$-\int_{\Theta} V_A\left(d_0, \theta\right) dF(\theta) + \int_{\Theta} V_A\left(d\left(\theta\right), \theta\right) dF(\theta) = \nu'(e). \tag{8}$$

By (8) the choice of the uninformed agent d_0 determines the optimal effort level $e\left(d_0\right)$. Consider the type 1 optimal delegation set. Then we have $\nu'(e(d_0)) = \frac{1}{2}\int_{d_0}^{\overline{\theta}} \left(d_0 - \theta\right)^2 dF(\theta)$. Thus $\nu''(e\left(d_0\right))e'\left(d_0\right) = \int_{d_0}^{\overline{\theta}} \left(d_0 - \theta\right) dF(\theta) < 0$ and we have $e'\left(d_0\right) < 0$. Let us assume that the optimal choice of the uninformed agent is d_0^* when $e = 0$. Consider the type 1 optimal delegation set determined by $d_0^* - \varepsilon$, where $\varepsilon > 0$. The corresponding effort level is defined by (8) is $e(d_0^* - \varepsilon)$. The unconstrained principal's payoff is

$$V(d_0^* - \varepsilon) = -\frac{p - e(d_0^* - \varepsilon)}{2}\int_{\underline{\theta}}^{\overline{\theta}} \left(d_0^* - \varepsilon - \theta - b\right)^2 dF(\theta) -$$

$$\frac{1 - p + e(d_0^* - \varepsilon)}{2}\left\{\int_{\underline{\theta}}^{d_0' - \varepsilon} \left(d_0^* - \varepsilon - \theta - b\right)^2 dF(\theta) + \int_{d_0' - \varepsilon}^{\overline{\theta}} b^2 dF(\theta)\right\}.$$

The derivative of $V(d_0^* - \varepsilon)$ with respect to ε evaluated at $\varepsilon = 0$ is $-\frac{\dot{e}(d_0^*)}{2}\int_{d_0}^{\overline{\theta}} \left(d_0^* - \theta - b\right)^2 dF(\theta) > 0$. We summarize:

Proposition 4 *Assume $b \in \left(b_2, b_{\max}\right)$. If the agent can exert effort in order to increase the probability of being informed then:*

a) the agent exerts the positive effort level;

b) the optimal delegation set involves more delegation to the agent than when the effort choice is inaccessible.

By Proposition 3 the principal benefits from the agent's effort. In order to induce the agent to collect information, the principal rewards the agent with more discretion. This result is complementary to the one in Szalay (2005) where $b = 0$.

Proofs

Proof of Lemma 5. Consider the first-order condition with respect to d_0, $p\frac{\partial V_0}{\partial d_0} + (1-p)\frac{\partial V_{\text{inf}}}{\partial d_0} = 0$. Because $\frac{\partial V_0}{\partial d_0} = -(d_0 - E(\theta) - b)$ we have to show that $\frac{\partial V_{\text{inf}}}{\partial d_0} < 0$. Consider first the type 1 optimal delegation set. Because $d_0 > \theta^*$ we have $\frac{\partial V_{\text{inf}}}{\partial d_0} = -\left\{\int_{\underline{\theta}}^{d_0} F(\theta) d\theta - bF(d_0)\right\} < 0$.

Consider the type 2 optimal delegation set D, $D = \left\{\{2\theta' - d_0\} \cup \left[d_0, \overline{\theta}\right], d_0\right\}$. We have $\theta^* \geq 2\theta' - d_0$. Indeed if $\theta^* < 2\theta' - d_0$ then for the set $\widetilde{D} = \left\{[\theta^*, 2\theta' - d_0] \cup \left[d_0, \overline{\theta}\right], d_0\right\}$ we have $V_0(\widetilde{D}) = V_0(D)$ and $V_{\text{inf}}(\widetilde{D}) > V_{\text{inf}}(D)$. Contradiction. The derivative

$$\frac{\partial V_{\text{inf}}}{\partial d_0} = -\frac{1}{2}\left[2bF(\theta') - bF(d_0) - \int_{\underline{\theta}}^{\theta'} F(\theta)d\theta + \int_{\theta'}^{d_0} F(\theta)d\theta\right] =$$

$$-\frac{1}{2}\left[2bF(\theta') - bF(d_0) - \int_{\underline{\theta}}^{2\theta'-d_0} F(\theta)d\theta - \int_{2\theta'-d_0}^{\theta'} F(\theta)d\theta + \int_{\theta'}^{d_0} F(\theta)d\theta\right]$$

Because $\widehat{\theta} \geq 2\theta' - d_0$ and the function $F(\theta)$ is log-concave we have by (4)

$$\frac{\partial V_{\text{inf}}}{\partial d_0} \leq -\frac{1}{2}\left[2bF(\theta') - bF(d_0) - bF(2\theta' - d_0) - \int_{2\theta'-d_0}^{\theta'} F(\theta)d\theta + \int_{\theta'}^{d_0} F(\theta)d\theta\right] < 0.$$

For a contract of type 3 we have immediately

$$\frac{\partial V_{\text{inf}}}{\partial d_0} = -\frac{1}{2}\left[2bF(\theta') - bF(d_0) - bF(2\theta' - d_0) - \int_{2\theta'-d_0}^{\theta'} F(\theta)d\theta + \int_{\theta'}^{d_0} F(\theta)d\theta\right] < 0.$$

■

Proof of Corollary 1. 1. If $d_0 < \theta^*$ consider the delegation set D^*. Because $\theta^* < E(\theta) + b$ the set D^* strictly improves V_0 and V_{inf}. Note that $q_0 = \theta^*$ only if $p = 0$.

2. If $d_1 > \theta^*$, then consider the set $\widetilde{D} = \left\{[\theta^*, d_1] \cup \left[d_0, \overline{\theta}\right], d_0\right\}$ which has the same uninformed decision d_0 and strictly improves V_{inf}.

3. From the first-order condition for d_1 we obtain $d_1 = \theta^*$. ■

Proof of Proposition 2. Note that the first-order conditions are sufficient for all three optimization problems.[2] Thus optimal $d_0^{(i)}(b)$ are defined by the first-order conditions. Consider $b > b_2^*$, then using the first-order condition $\frac{\partial V_1}{\partial d_0}(d_0^{(1)}(b), b) = 0$ and (6) we obtain

$$\frac{\partial V_2}{\partial d_0}(d_0^{(1)}) = F(E(\theta))\left[\frac{\int_{\underline{\theta}}^{E(\theta)} F(\theta)\, d\theta}{F(E(\theta))} - b\right] < 0.$$

For any fixed b, $V_2(d_0, b)$ is a convex function of d_0 and $\frac{\partial V_2}{\partial d_0}(d_0^{(2)}(b), b) = 0$. Hence $d_0^{(1)}(b) > d_0^{(2)}(b)$ for all $b \in [b_2^*, b_{\max}]$. Consider $V_i(b) = V_i(d_0^{(i)}(b), b)$ as functions of b. Using the Envelope theorem the derivative of $V_1(b)$ is

$$\frac{dV_1(b)}{db} = b(1-p)(1 - F(d_0^{(1)})) \tag{9}$$

[2]Proof is available upon request. The idea is that even though V_i are not concave in d_0, the functions $\frac{(\partial V_i/\partial d_0)}{F(d_0)}$ are strictly decreasing functions of d_0.

and

$$\frac{dV_2(b)}{db} = -b(1-p)\left(\left(E(\theta) - d_0^{(2)}(b)\right)F(E(\theta)) - \left(bF(E(\theta)) - \int_{\underline{\theta}}^{E(\theta)} F(\theta)\,d\theta\right)\right)(1 - F(d_0^{(2)})).$$

By (6) we have $\frac{dV_1(b)}{db} > \frac{dV_2(b)}{db}$ for all $b \in [b_2^*, b_{\max}]$. Note that $V_1(d_0^{(1)}(b_2^*), b_2^*) = V_2(d_0^{(1)}(b_2^*), b_2^*)$. For $b \geq b_2^*$ consider the delegation set of type 1 $D(b) = \left\{\left[d_0^{(1)}(b), \overline{\theta}\right], d_0^{(1)}(b)\right\}$ and of type 2 $D'(b) = \left\{\left(2E(\theta) - d_0^{(1)}(b)\right) \cup \left[d_0^{(1)}(b), \overline{\theta}\right], d_0^{(1)}(b)\right\}$. We have $V_0(D) = V_0(D')$. Hence

$$V_2(D'(b), b) - V_1(D(b), b) = \frac{1-p}{2}\int_{\underline{\theta}}^{E(\theta)} \left[(d_0^{(1)}(b) - \theta - b)^2 - (2E(\theta) - d_0^{(1)}(b) - \theta - b)^2\right] dF(\theta) =$$

$$(1-p)\int_{\underline{\theta}}^{E(\theta)} (d_0^{(1)}(b) - E(\theta))(E(\theta) - \theta - b)\,dF(\theta) = 2p(d_0^{(1)}(b) - E(\theta))\int_{\underline{\theta}}^{E(\theta)} (E(\theta) - \theta - b)\,dF(\theta).$$

Note that for $b = b_2^*$ we have $\int_{\underline{\theta}}^{E(\theta)} (E(\theta) - \theta - b_2^*)\,dF(\theta) = 0$. Thus $V_2(d_0^{(2)}(b_2^*), b_2^*) \geq V_2(d_0^{(1)}(b_2^*), b_2^*) = V_1(d_0^{(1)}(b_2^*), b_2^*)$. Therefore there exist $b_2 \geq b_2^*$ such that $V_2(d_0^{(2)}(b_2), b_2) = V_1(d_0^{(1)}(b_2), b_2)$. Similarly we establish that $V_3(d_0^{(3)}(b), b) > V_2(d_0^{(2)}(b), b)$ for $b \in [0, b_1)$. ■

Proof Proposition 3 Consider for simplicity the type 1 optimal delegation set. The derivative of the principal's payoff with respect to p:

$$\frac{dV_1}{dp}\left(d_0^{(1)}(p), p\right) = \frac{\partial V_1}{\partial d_0}\left(d_0^{(1)}(p), p\right)\frac{dd_0^{(1)}(p)}{dp} - \frac{1}{2}\int_{\underline{\theta}}^{\overline{\theta}} (d_0 - \theta - b)^2 dF(\theta)$$

$$+\frac{1}{2}\left[\int_{\underline{\theta}}^{d_0} (d_0 - \theta - b)^2 dF(\theta) + \int_{d_0}^{\overline{\theta}} b^2 dF(\theta)\right].$$

By the first-order condition we have $\frac{\partial V_1}{\partial d_0}\left(d_0^{(1)}(p), p\right) = 0$ and thus

$$\frac{dV_1}{dp}\left(d_0^{(1)}(p), p\right) = \int_{d_0}^{\overline{\theta}} \left(b^2 - (d_0 - \theta - b)^2\right) dF(\theta) = \int_{d_0}^{\overline{\theta}} (2b - d_0 + \theta)(d_0 - \theta)dF(\theta) < 0.$$

For the derivative of the agent's payoff with respect to p we have

$$-\frac{1}{2}\int_{\underline{\theta}}^{\overline{\theta}} (d_0 - \theta)^2 dF(\theta) - \frac{dd_0^{(1)}(p)}{dp}\left[p(d_0 - E(\theta)) + (1-p)\left(d_0 F(d_0) - \int_{\underline{\theta}}^{d_0} \theta dF(\theta)\right)\right] =$$

$$-\frac{1}{2}\int\limits_{\underline{\theta}}^{\overline{\theta}}(d_0-\theta)^2dF(\theta)-\frac{dd_0^{(1)}(p)}{dp}\left[p(d_0-E(\theta))+(1-p)\int\limits_{\underline{\theta}}^{d_0}F(\theta)d\theta\right]<0,$$

because $\frac{dd_0^{(1)}(p)}{dp}>0$ and $d_0-E(\theta)>0$.

■

Proof Proposition 4 *a)* Consider the type 1 optimal delegation set. Then (8) is $\nu'(e(d_0)) = \frac{1}{2}\int_{d_0}^{\overline{\theta}}(d_0-\theta)^2\,dF(\theta)$. Thus $\nu''(e(d_0))e'(d_0) = \int_{d_0}^{\overline{\theta}}(d_0-\theta)\,dF(\theta) < 0$ and we have $e'(d_0) < 0$. Let us assume that the optimal choice of the uninformed agent is d_0^* when $e=0$. Consider the type 1 optimal delegation set determined by $d_0^*-\varepsilon$, where $\varepsilon>0$ is small enough. The corresponding effort level is $e(d_0^*-\varepsilon)$. The unconstrained principal's payoff is

$$V(d_0^*-\varepsilon) = -\frac{p-e(d_0^*-\varepsilon)}{2}\int_{\underline{\theta}}^{\overline{\theta}}(d_0^*-\varepsilon-\theta-b)^2\,dF(\theta)-$$

$$\frac{1-p+e(d_0^*-\varepsilon)}{2}\left\{\int_{\underline{\theta}}^{d_0'-\varepsilon}(d_0^*-\varepsilon-\theta-b)^2\,dF(\theta)+\int_{d_0'-\varepsilon}^{\overline{\theta}}b^2dF(\theta)\right\}.$$

The derivative of $V(d_0^*-\varepsilon)$ with respect to ε evaluated at $\varepsilon=0$ is $-\frac{\dot{e}(d_0^*)}{2}\int_{d_0}^{\overline{\theta}}(d_0^*-\theta-b)^2\,dF(\theta) > 0$.

b) Assume that $\widetilde{D}=\{[\underline{\theta},d_0],d_0\}$ and $d_0>d_0^*$, where the delegation set $D=\{[\underline{\theta},d_0^*],d_0^*\}$ is optimal for $e=0$. Then we have $V(D)>V(\widetilde{D})$. Contradiction. ■

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