Monitoring, Multiple Agents, and Organization Structure

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1 Introduction

This paper examines optimal contracts in a principal-agent model, in which a principal delegates constructing facilities, such as toll expressways, to one or two agents. Each of the agents is assumed to have private information about production costs, which depend on productivity and cost reduction efforts. We consider a setting in which a principal determines an organization between two possible structures, decides on residual claimancy, and chooses a monitoring instrument between input and cost monitoring. Under a decentralized structure, the principal contracts with the two agents. We show that the principal prefers to be a residual claimant, to choose input monitoring, and to obtain the largest payoff. If the principal grants residual claimancy to the agent and implements input monitoring, the principal obtains the lowest payoff. The principal obtains an intermediate payoff under cost monitoring irrespective of the choice of residual claimancy. Under an integrated organization, we show that the principal chooses to be residual claimant and to implement input monitoring and obtains the highest payoff. When implementing cost monitoring, the principal chooses an integrated organization and obtains a higher payoff than that under a decentralized organization.

Our work is motivated by the administrative reforms of the Japanese state-owned corporations that have been implemented under the Administrative and Fiscal Reforms since the early 1980's. In 1985, Nippon Telegraph and Telephone Public Corporation was privatized, and in 1999, it was divided into two regional companies. In 1987, Japan National Railways was privatized and divided into seven regional railway companies. Furthermore, in 2005, the Japan Highway Public Corporation (JH) was divided into three privatized expressway companies and one principal institution, the Japan Expressway Holding and Debt Repayment Agency (JEHDRA), which inherited nationwide expressway assets and liabilities from JH. Under contracts with JEHDRA, each of the three regional companies constructs expressways and collects the toll revenues, which JEHDRA repays the debt. These industries engendered debates about organizational reforms and the choice of monitoring instruments.

This paper studies optimal regulation policy regarding residual claimancy, monitoring instruments, and the organizational structure of such industries, and focuses on the following three related issues. First, we analyze issues related to the choice of residual claimancy. Second, we examine information consolidation versus decentralization. Third, we address a principal's optimal choice of monitoring instruments. We contribute to the literature on principal-multiple agents under asymmetric information by showing that under a decentralized structure, the principal prefers to be a residual claimant and to choose input monitoring. Under input monitoring, the principal chooses to be a residual claimant, and that by implementing cost monitoring, he obtains a higher payoff by choosing a fully consolidated organization than with a decentralized one.

This paper is closely related to the literature about information integration and decentralization. Baron and Besanko (1992) analyzed the optimal contract problem, in which a regulator (principal) organizes the production of a final good from two inputs, provided by one or two suppliers. They showed that when the costs of the two inputs are independently distributed, the optimal organization depends on the degree of complementarity or substitutability between the two inputs. Gilbert and Riordan (1995) showed that for complementary inputs, a principal is better off under integration than under decentralization. Dana (1993) analyzed a model in which a principal procures a product under either a decentralized organization or an integrated organization. He showed that the optimal organization structure depends on whether or not two agents' production costs are sufficiently positively correlated. Mookherjee and Tsumagari (2004) showed that integration dominates decentralization under complementarity when two inputs' costs are identically exponentially distributed and that when the two inputs are substitutes, a principal prefers decentralization to integration.

This paper also relates to the literature about monitoring in principal-agent models. Khalil and Lawarree (1995) examined an asymmetric information model, in which a principal can design residual claimancy and choose a monitoring instrument. They concluded that input monitoring, with a principal as residual claimant, yields the highest payoff to the principal, and that input monitoring, with the agent as residual claimant, yields the lowest payoff. They also showed that regardless of who is the residual claimant, output monitoring results in an intermediate payoff for a principal. While Khalil and Lawarree (1995) consider only one agent, our paper involves multiple ones .

The paper is organized as follows. In Section 2, we present the model and the basic assumptions. In Section 3, we characterize optimal contracts under two organizational structures. One is decentralization and the other is full consolidation. In Section 4, we compare these two organization structures. Section 5 provides conclusions.

2 Model

Suppose that a principal delegates the construction of facilities or infrastructure, such as toll expressways, to two agents, A and B. We assume that the project yields surplus S and revenue R, both of which are observable and verifiable. Without loss of generality, we assume that surplus S equals zero. The production cost of each agent depends on a productivity parameter, θ and a cost reduction effort, e. The parameters θ and e are each agent's private information. We assume that the cost function of agent k is given by

$$C^k = \theta^k - e^k, \quad k = A, B.$$

We assume θ^k takes one of these two values, $\theta^k \in \{\theta_L^k, \theta_H^k\}$ and $0 < \theta_L^k < \theta_H^k$, with probabilities p or $1-p$, respectively, $0 < p < 1$.

Let p_{ij} denote the joint probability of agent A's parameter θ_i^A and agent B's parameter θ_j^B, $i, j = L, H$, $i \neq j$. For simplicity, we assume that θ^A and θ^B are independent. We further assume that the disutility of cost reduction effort e is given by $\varphi(e) = \gamma \frac{e^2}{2}$, $\gamma > 0$. Let e_{ij}^k denote agent k's effort when agent A's parameter is θ_i^A and agent B's parameter θ_i^B.

We analyze the following two organizational structures. First we consider a decentralized organization in which a principal contracts with the two agents. The second structure is what we refer to as a fully consolidated organization, where a principal contracts with agents who exert efforts in a single division. Here, the disutility of exerting efforts is given by $\varphi(e_{ij})$.

Under each of the two organizational structures, we assume that the principal can determine residual claimancy (the principal or the agents) and choose a monitoring instrument (input or cost). With input monitoring, the principal can observe e and enforce the optimal effort level. With cost monitoring, the principal can verify the realized cost C.

Remark: In this paper, we focus on a case where the principal maximizes his payoff. This maximization problem is equivalent to a minimization of costs, because in our setting, revenues are public information. This assumption can be justified, because in industries such as express highways, fixed costs are large but private, and revenues are verifiable. Thus, cost monitoring in our model is the same as output monitoring in Khalil and Lawarree (1995).

2.1 Decentralization

Principal as Residual Claimant The principal receives revenue R, bears costs $\theta_i^A - e_{ij}^A$ and $\theta_j^B - e_{ij}^B$, and pays a net monetary transfer t_{ij}^A and t_{ij}^B to the two agents. Thus, his expected payoff Π^G is given by

$$\Pi^G = R - \sum p_{ij}(\theta_i^A - e_{ij}^A + t_{ij}^A + \theta_j^B - e_{ij}^B + t_{ij}^B).$$

We note that

$$p_{LL} = p^2, \quad p_{LH} = p(1-p), \quad p_{HL} = p(1-p), \quad \text{and } p_{HH} = (1-p)^2.$$

Each agent obtains a monetary transfer t_{ij}^A or t_{ij}^B and exerts cost reduction effort e_{ij}^A or e_{ij}^B. Thus, each agent's expost payoff U_{ij}^G is

$$U_{ij}^G = t_{ij}^A - \gamma \frac{(e_{ij}^A)^2}{2} \text{ and } U_{ij}^G = t_{ij}^B - \gamma \frac{(e_{ij}^B)^2}{2}.$$

Agent as Residual Claimant The principal obtains monetary transfers τ_{ij}^A and τ_{ij}^B from the agents. The expected payoff Π^F is given by

$$\Pi^F = \sum p_{ij}(\tau_{ij}^A + \tau_{ij}^B).$$

We assume that each agent earns revenue $\frac{R}{2}$, incurs cost $\theta_i^A - e_{ij}^A$ or $\theta_j^B - e_{ij}^B$, pays a transfer τ_{ij}^A or τ_{ij}^B, and exerts a cost reduction effort e_{ij}^A or e_{ij}^B. Thus, each agent's *ex post* payoff U_{ij}^F is given by

$$U_{ij}^F = \frac{R}{2} - (\theta_i^A - e_{ij}^A) - \gamma\frac{(e_{ij}^A)^2}{2} - \tau_{ij}^A$$

and

$$U_{ij}^F = \frac{R}{2} - (\theta_j^B - e_{ij}^B) - \gamma\frac{(e_{ij}^B)^2}{2} - \tau_{ij}^B.$$

2.2 Full Consolidation

Principal as Residual Claimant The principal obtains revenue R, bears observed cost $\theta_i^A + \theta_j^B - e_{ij}$ and pays monetary transfer t_{ij} to the agent. The expected payoff π^{*G} is given by

$$\pi^{*G} = R - \sum p_{ij}(\theta_i^A + \theta_j^B - e_{ij} + t_{ij}).$$

The agent earns t_{ij} and exerts effort e_{ij} in an integrated division. The agent's payoff u_{ij}^{*G} is given by

$$u_{ij}^{*G} = t_{ij} - \gamma\frac{(e_{ij})^2}{2}.$$

Agent as Residual Claimant The principal obtains monetary transfer τ_{ij}. The expected payoff π^{*F} is given by

$$\pi^{*F} = \sum p_{ij}\tau_{ij}.$$

The agent earns revenue R, incurs cost $\theta_i^A + \theta_j^B - e_{ij}$, pays transfer τ_{ij} to the principal, and exerts effort e_{ij}. The agent's payoff u_{ij}^{*F} is given by

$$u_{ij}^{*F} = R - (\theta_i^A + \theta_j^B - e_{ij}) - \gamma\frac{(e_{ij})^2}{2} - \tau_{ij}.$$

2.3 Timing

The timing of the contracting game is as follows:

At t = 1, the principal chooses an organization structure (a decentralization organization or a consolidated organization). The principal also determines who is a residual claimant and chooses a monitoring instrument between input and cost monitoring.

At t = 2, nature chooses productivity parameters θ_i^A and θ_j^B. Each of the two agents observes its type, either low cost L or high cost H.

At t = 3, the principal offers a contract to each agent, who either accepts or rejects it.

At t = 4, each of the two agents exerts a cost reduction effort e, and production costs C^A and C^B are realized.

At t = 5, the monetary transfers between the principal and the agents take place.

3 Characterization of Optimal Contracts

In this section, under each of the two organizational structures, we examine optimal contracts for the following four cases.

Case 1: A principal is the residual claimant and monitors effort.

Case 2: A principal is the residual claimant and monitors cost.

Case 3: An agent is the residual claimant, whose effort is monitored.

Case 4: An agent is the residual claimant, whose cost is monitored.

3.1 Decentralization

3.1.1 Principal as Residual Claimant

Case 1: Input Monitoring The principal's problem is to maximize his payoff, subject to the constraints described below.

$$\Pi^G = R - \sum p_{ij}(\theta_i^A - e_{ij}^A + t_{ij}^A + \theta_j^B - e_{ij}^B + t_{ij}^B).$$

The principal faces interim incentive compatibility constraints,

$$\sum p_{Lj}\left[t_{Lj}^A - \gamma\frac{(e_{Lj}^A)^2}{2}\right] \geq \sum p_{Lj}\left[t_{Hj}^A - \gamma\frac{(e_{Hj}^A)^2}{2}\right]$$

$$\text{and} \quad \sum p_{iL}\left[t_{iL}^B - \gamma\frac{(e_{iL}^B)^2}{2}\right] \geq \sum p_{iL}\left[t_{iH}^B - \gamma\frac{(e_{iH}^B)^2}{2}\right],$$

and participation constraints,

$$t_{Hj}^A - \gamma\frac{(e_{Hj}^A)^2}{2} \geq 0$$

$$\text{and} \quad t_{iH}^B - \gamma\frac{(e_{iH}^B)^2}{2} \geq 0, \quad i, j = L, H.$$

Let e^{FB} denote the first best effort level.

Lemma 1: The optimal contract effects

$$e_{ij}^A = e_{ij}^B = \frac{1}{\gamma} = e^{FB},$$

$$t_{Hj}^{A} = \gamma \frac{(e_{Hj}^{A})^2}{2},$$

$$\text{and} \quad t_{iH}^{B} = \gamma \frac{(e_{iH}^{B})^2}{2}, \ \ i, j = L, H.$$

Proof: See the Appendix.

Case 2: Cost Monitoring The principal's objective function is the same as in case 1. Interim incentive compatibility constraints and participation constraints are given by

$$\sum p_{Lj} \left[t_{Lj}^{A} - \gamma \frac{(e_{Lj}^{A})^2}{2} \right] \geq \sum p_{Lj} \left[t_{Hj}^{A} - \gamma \frac{(\hat{e}_{Hj}^{A})^2}{2} \right],$$

$$\sum p_{iL} \left[t_{iL}^{B} - \gamma \frac{(e_{iL}^{B})^2}{2} \right] \geq \sum p_{iL} \left[t_{iH}^{B} - \gamma \frac{(\hat{e}_{iH}^{B})^2}{2} \right],$$

$$t_{Hj}^{A} - \gamma \frac{(e_{Hj}^{A})^2}{2} \geq 0$$

$$\text{and} \quad t_{iH}^{B} - \gamma \frac{(e_{iH}^{B})^2}{2} \geq 0, \ \ i, j = L, H,$$

where we have $\hat{e}_{Hj}^{A} = e_{Hj}^{A} - (\theta_H - \theta_L)$ and $\hat{e}_{iH}^{B} = e_{iH}^{B} - (\theta_H - \theta_L)$.

Lemma 2: The optimal contract effects

$$t_{Hj}^{A} - \gamma \frac{(e_{Hj}^{A})^2}{2},$$

$$t_{iH}^{B} - \gamma \frac{(e_{iH}^{B})^2}{2},$$

$$\begin{aligned} p_{LL} t_{LL}^{A} + p_{LH} t_{LH}^{A} = p_{LL} \gamma & \left[\frac{(e_{LL}^{A})^2}{2} + (\theta_H - \theta_L)\, e_{HL}^{A} - \frac{(\theta_H - \theta_L)^2}{2} \right] \\ + p_{LH} \gamma & \left[\frac{(e_{LH}^{A})^2}{2} + (\theta_H - \theta_L)\, e_{HH}^{A} - \frac{(\theta_H - \theta_L)^2}{2} \right], \end{aligned}$$

$$\begin{aligned} p_{LL} t_{LL}^{B} + p_{HL} t_{HL}^{B} = p_{LL} \gamma & \left[\frac{(e_{LL}^{B})^2}{2} + (\theta_H - \theta_L)\, e_{LH}^{B} - \frac{(\theta_H - \theta_L)^2}{2} \right] \\ + p_{HL} \gamma & \left[\frac{(e_{HL}^{B})^2}{2} + (\theta_H - \theta_L)\, e_{HH}^{B} - \frac{(\theta_H - \theta_L)^2}{2} \right], \end{aligned}$$

$$e_{LL}^{A} = e_{LH}^{A} = e_{LL}^{B} = e_{HL}^{B} = \frac{1}{\gamma},$$

$$\text{and} \quad e_{HL}^{A} = e_{LH}^{B} = e_{HH}^{A} = e_{HH}^{B} = \frac{1}{\gamma} - \frac{p}{1-p} (\theta_H - \theta_L).$$

Proof: See the Appendix.

Note that because $e > 0$ and $e^A_{Hj} - (\theta_H - \theta_L) = e^B_{iH} - (\theta_H - \theta_L) > 0$, we must have a restriction on the parameters' values,

$$\theta_H - \theta_L < 1 - p.$$

3.1.2 Agent as Residual Claimant

Case 3: Input Monitoring The principal's problem is to maximize his payoff Π^F,

$$\Pi^F = \sum p_{ij}(\tau^A_{ij} + \tau^B_{ij})$$

subject to

$$\sum p_{Lj}\left[\frac{R}{2} - (\theta_L - e^A_{Lj}) - \gamma\frac{(e^A_{Lj})^2}{2} - \tau^A_{Lj}\right] \geq \sum p_{Lj}\left[\frac{R}{2} - (\theta_L - e^A_{Hj}) - \gamma\frac{(e^A_{Hj})^2}{2} - \tau^A_{Hj}\right],$$

$$\sum p_{iL}\left[\frac{R}{2} - (\theta_L - e^B_{iL}) - \gamma\frac{(e^B_{iL})^2}{2} - \tau^B_{iL}\right] \geq \sum p_{iL}\left[\frac{R}{2} - (\theta_L - e^B_{iH}) - \gamma\frac{(e^B_{iH})^2}{2} - \tau^B_{iH}\right],$$

$$\frac{R}{2} - (\theta_H - e^B_{iH}) - \gamma\frac{(e^B_{iH})^2}{2} - \tau^B_{iH} \geq 0,$$

$$\text{and } \frac{R}{2} - (\theta_H - e^A_{Hj}) - \gamma\frac{(e^A_{Hj})^2}{2} - \tau^A_{Hi} \geq 0, \quad i, j = L, H.$$

Lemma 3: The optimal contract effects

$$\tau^A_{Hj} = \frac{R}{2} - (\theta_H - e^A_{Hj}) - \gamma\frac{(e^A_{Hj})^2}{2},$$

$$\tau^B_{iH} = \frac{R}{2} - (\theta_H - e^B_{iH}) - \gamma\frac{(e^B_{iH})^2}{2},$$

$$p_{LL}\tau_{LL} + p_{LH}\tau_{LH} = p_{LL}\left[\frac{R}{2} - \theta_H + e^A_{LL} - \gamma\frac{(e^A_{LL})^2}{2}\right] + p_{LH}\left[\frac{R}{2} - \theta_H + e^A_{LH} - \gamma\frac{(e^A_{HL})^2}{2}\right],$$

$$p_{LL}\tau_{LL} + p_{HL}\tau_{HL} = p_{LL}\left[\frac{R}{2} - \theta_H + e^B_{LL} - \gamma\frac{(e^B_{LL})^2}{2}\right] + p_{HL}\left[\frac{R}{2} - \theta_H + e^B_{HL} - \gamma\frac{(e^B_{HL})^2}{2}\right],$$

and

$$e^A_{ij} = e^B_{ij} = e^{FB} = \frac{1}{\gamma}, \quad i, j = L, H.$$

Proof: See the Appendix.

Case 4: Cost monitoring The principal's problem is to maximize

$$\Pi^F = \sum p_{ij}(\tau_{ij}^A + \tau_{ij}^B),$$

facing the following interim incentive compatibility constraints and participation constraints:

$$\sum p_{Lj}\left[\frac{R}{2} - (\theta_L - e_{Lj}^A) - \gamma\,\frac{(e_{Lj}^A)^2}{2} - \tau_{Lj}^A\right] \geq \sum p_{Lj}\left[\frac{R}{2} - (\theta_L - e_{Hj}^A) - \gamma\,\frac{(\hat{e}_{Hj}^A)^2}{2} - \tau_{Hj}^A\right],$$
$$\sum p_{iL}\left[\frac{R}{2} - (\theta_L - e_{iL}^B) - \gamma\,\frac{(e_{iL}^B)^2}{2} - \tau_{iL}^B\right] \geq \sum p_{iL}\left[\frac{R}{2} - (\theta_L - e_{iH}^B) - \gamma\,\frac{(\hat{e}_{iH}^B)^2}{2} - \tau_{iH}^B\right],$$

$$\frac{R}{2} - (\theta_H - e_{iH}^A) - \gamma\,\frac{(e_{iH}^B)^2}{2} - \tau_{iH}^B \geq 0,$$
$$\text{and}\quad \frac{R}{2} - (\theta_H - e_{Hj}^A) - \gamma\,\frac{(e_{Hj}^A)^2}{2} - \tau_{Hj}^A \geq 0, \quad i, j = L, H.$$

where we have $\hat{e}_{Hj}^A = e_{Hj}^A - (\theta_H - \theta_L)$ and $\hat{e}_{iH}^B = e_{iH}^B - (\theta_H - \theta_L)$.

Lemma 4: The optimal contract effects

$$\tau_{Hj}^A = \frac{R}{2} - (\theta_H - e_{Hj}^A) - \gamma\,\frac{(e_{Hj}^A)^2}{2},$$
$$\tau_{iH}^B = \frac{R}{2} - (\theta_H - e_{iH}^B) - \gamma\,\frac{(e_{iH}^B)^2}{2},$$

$$p_{LL}\tau_{LL} + p_{LH}\tau_{LH} = p_{LL}\left[\frac{R}{2} - \theta_L + e_{LL}^A - \gamma\,\frac{(e_{LL}^A)^2}{2} - \gamma\,(\theta_H - \theta_L)\,e_{HL}^A + \gamma\,\frac{(\theta_H - \theta_L)^2}{2}\right]$$
$$+ p_{LH}\left[\frac{R}{2} - \theta_L + e_{LH}^A - \gamma\,\frac{(e_{LH}^A)^2}{2} - \gamma\,(\theta_H - \theta_L)\,e_{HH}^A + \gamma\,\frac{(\theta_H - \theta_L)^2}{2}\right]$$

$$p_{LL}\tau_{LL}^B + p_{HL}\tau_{HL}^B = p_{LL}\left[\frac{R}{2} - \theta_L + e_{LL}^B - \gamma\,\frac{(e_{LL}^B)^2}{2} - \gamma\,(\theta_H - \theta_L)\,e_{LH}^B + \gamma\,\frac{(\theta_H - \theta_L)^2}{2}\right]$$
$$+ p_{HL}\left[\frac{R}{2} - \theta_L + e_{HL}^B - \gamma\,\frac{(e_{HL}^B)^2}{2} - \gamma\,(\theta_H - \theta_L)\,e_{HH}^B + \gamma\,\frac{(\theta_H - \theta_L)^2}{2}\right]$$

$$e_{LL}^A = e_{LH}^A = e_{LL}^B = e_{HL}^B = e_{HL}^A = e_{HL}^B = \frac{1}{\gamma},$$
$$\text{and}\quad e_{HH}^A = e_{HH}^B = 1 - \frac{p}{1-p}\,(\theta_H - \theta_L).$$

Proof: See the Appendix.

Note that we must have a restriction on the parameters' values,

$$\theta_H - \theta_L < 1 - p.$$

3.2 Comparison

In what follows, we assume $\gamma = 1$ for simplicity.

The principal's expected payoff under case 1 Π^{GI} is given by

$$\Pi^{GI} = R - 2\theta_H + 1 + 2p(\theta_H - \theta_L).$$

The principal's expected payoff under case 2 Π^{GO} is given by

$$\Pi^{GO} = R - 2\theta_H + 1 + \frac{p}{1-p}(\theta_H - \theta_L)^2.$$

The principal's payoff under case 3 Π^{FI} is

$$\Pi^{FI} = R - 2\theta_H + 1.$$

The principal's payoff under case 4 Π^{FO} is

$$\Pi^{FO} = R - 2\theta_H + 1 + \frac{p}{1-p}(\theta_H - \theta_L)^2.$$

Comparing the principal's payoffs under the four cases described above, we obtain the following result.

Proposition 1:

$$\Pi^{FI} < \Pi^{GO} = \Pi^{FO} < \Pi^{GI}.$$

Proof:

$$\Pi^{GO} - \Pi^{FI} = \frac{p}{1-p}(\theta_H - \theta_L)^2 > 0.$$

$$\Pi^{GI} - \Pi^{FI} = 2p(\theta_H - \theta_L)^2 > 0.$$

Because $\theta_H - \theta_L < 1 - p$, we have

$$\Pi^{GI} - \Pi^{GO} = p(\theta_H - \theta_L)\left[2 - \frac{p}{1-p}(\theta_H - \theta_L)\right]$$
$$> p(\theta_H - \theta_L) > 0.$$

3.3 Consolidated Organization

3.3.1 Principal as Residual Claimant

Case 1: Input Monitoring The principal's problem is to maximize

$$\pi^{*G} = R - \sum p_{ij}(\theta_i + \theta_j - e_{ij}^A + t_{ij}).$$

The principal faces the following ex post incentive compatibility constraints and participation constraint:

$$t_{Lj}-\gamma\frac{(e_{Lj}^{A})^2}{2}\geq t_{Hj}-\gamma\frac{(e_{Hj})^2}{2},$$
$$t_{iL}-\gamma\frac{(e_{iL})^2}{2}\geq t_{iH}-\gamma\frac{(e_{iH})^2}{2},$$
$$t_{LL}-\gamma\frac{(e_{LL})^2}{2}\geq t_{HH}-\gamma\frac{(e_{HH}^{B})^2}{2},\quad i,j=L,H,$$

$$t_{LL}-\gamma\frac{(e_{LL})^2}{2}\geq 0$$
$$t_{LH}-\gamma\frac{(e_{LH})^2}{2}\geq 0.$$
$$t_{HL}-\gamma\frac{(e_{HL})^2}{2}\geq 0.$$
$$\text{and}\quad t_{HH}-\gamma\frac{(e_{HH})^2}{2}\geq 0.$$

Lemma 5: The optimal contract effects

$$t_{ij}=\gamma\frac{(e_{ij})^2}{2},$$

and

$$e_{ij}=\frac{1}{\gamma},\quad i,j=L,H.$$

Case 2: Cost Monitoring The principal's problem is to maximize

$$\pi^{*G}=R-\sum p_{ij}(\theta_i+\theta_j-e_{ij}+t_{ij}).$$

He faces the following *ex* post incentive compatibility constraints and participation constraints:

$$t_{Lj}-\gamma\frac{(e_{Lj}^{A})^2}{2}\geq t_{Hj}-\gamma\frac{(\hat{e}_{Hj}^{A})^2}{2},$$
$$t_{Lj}-\gamma\frac{(e_{iL})^2}{2}\geq t_{iH}-\gamma\frac{(\hat{e}_{iH})^2}{2},$$
$$t_{LL}-\gamma\frac{(e_{LL})^2}{2}\geq t_{HH}-\gamma\frac{(\hat{e}_{HH})^2}{2},$$

$$\text{and}\quad t_{ij}-\gamma\frac{(e_{ij})^2}{2}\geq 0,\quad i,j=L,H,$$

where we have $\hat{e}_{Hj}^{A}=e_{Hj}^{A}-(\theta_H-\theta_L)$ and $\hat{e}_{iH}^{B}=e_{iH}^{B}-(\theta_H-\theta_L)$.

Lemma 6: The optimal contract effects

$$t_{HH}=\gamma\frac{(e_{HH})^2}{2},$$
$$t_{LH}=\gamma\frac{(e_{LH})^2}{2},$$
$$t_{HL}=\gamma\frac{(e_{HL})^2}{2},$$

$$t_{LL} = \gamma\left[\frac{(e_{LL})^2}{2} + (\theta_H - \theta_L)(e_{LH} + e_{HH}) - (\theta_H - \theta_L)^2\right],$$

$$e_{LL} = e_{LH} = e_{LH} = \frac{1}{\gamma},$$

$$\text{and} \quad e_{HH} = \frac{1}{\gamma} - \frac{2p}{(1-p)^2}(\theta_H - \theta_L).$$

Note that because $e > 0$, we must have $e_{HH} = e_{HH} - (\theta_H - \theta_L) > 0$, and it follows that

$$\theta_H - \theta_L > \frac{(1-p)^2}{p^2+1}.$$

3.3.2 Agent as Residual Claimant

Case 3: Input Monitoring The principal's problem is to maximize

$$\pi^{*F} = \sum p_{ij}\tau_{ij}$$

subject to the incentive compatibility constraints

$$R - (\theta_i + \theta_j - e_{ij}) - \gamma\frac{(e_{ij})^2}{2} - \tau_{ij}$$
$$\geq R - (\theta_i + \theta_j - e_{mn}) - \gamma\frac{(e_{mn})^2}{2} - \tau_{mn}, \quad i, j = L, H, \text{ and } m, n = L, H,$$

and the participation constraints

$$R - (\theta_i + \theta_j - e_{ij}) - \gamma\frac{(e_{ij})^2}{2} - \tau_{ij} \geq 0, \quad i, j = L, H.$$

Lemma 7: The optimal contract effects

$$\tau_{HH} = R - (2\theta_H - e_{HH}) - \gamma\frac{(e_{HH})^2}{2},$$
$$\tau_{HL} = R - (2\theta_H - e_{HL}) - \gamma\frac{(e_{HL})^2}{2},$$
$$\tau_{LH} = R - (2\theta_H - e_{LH}) - \gamma\frac{(e_{LH})^2}{2},$$

$$\tau_{LL} = R - (2\theta_H - e_{LL}) - \gamma\frac{(e_{LL})^2}{2},$$

and

$$e_{ij} = \frac{1}{\gamma}, \quad i, j = L, H.$$

Case 4: Cost Monitoring The principal's problem is to maximize

$$\pi^{*F} = \sum p_{ij}\tau_{ij}.$$

He faces the following *ex post* incentive compatibility constraints and participation constraints:

$$R-(\theta_L+\theta_j-e_{Lj})-\gamma\,\frac{(e_{Lj})^2}{2}-\tau_{Lj}\geq R-(\theta_L+\theta_j-\hat{e}_{Hj})-\gamma\,\frac{\hat{e}_{Hj}}{2}-\tau_{Hj},$$

$$R-(\theta_i+\theta_L-e_{iL})-\gamma\,\frac{(e_{iL})^2}{2}-\tau_{iL}\geq R-(\theta_i+\theta_L-\hat{e}_{iH})-\gamma\,\frac{(\hat{e}_{iH})^2}{2}-\tau_{iH},$$

$$R-(\theta_L+\theta_L-e_{LL})-\gamma\,\frac{(e_{LL})^2}{2}-\tau_{LL}\geq R-(\theta_L+\theta_L-\hat{e}_{HH})-\gamma\,\frac{(\hat{e}_{HH})^2}{2}-\tau_{HH},$$

and $R-(\theta_H+\theta_H-e_{HH})-\gamma\,\frac{(e_{HH})^2}{2}-\tau_{HH}\geq 0,$

where $\hat{e}_{Lj}=e_{Hj}-(\theta_H-\theta_L)$ and $\hat{e}_{iH}=e_{iH}-(\theta_H-\theta_L)$.

Lemma 8: The optimal contract effects

$$\tau_{HH}=R-(2\theta_H-e_{HH})-\gamma\,\frac{(e_{HH})^2}{2},$$

$$\tau_{LH}=R-(\theta_L+\theta_H-e_{LH})-\gamma\left[\frac{(e_{LH})^2}{2}+(\theta_H-\theta_L)\,e_{HH}-\frac{(\theta_H-\theta_L)^2}{2}\right],$$

$$\tau_{HL}=R-(\theta_H+\theta_L-e_{HL})-\gamma\left[\frac{(e_{HL})^2}{2}+(\theta_H-\theta_L)\,e_{HH}-\frac{(\theta_H-\theta_L)^2}{2}\right],$$

$$\tau_{LL}=R-(2\theta_L-e_{LL})-\gamma\left[\frac{(e_{LL})^2}{2}+(\theta_H-\theta_L)(e_{LH}+e_{HH})-(\theta_H-\theta_L)^2\right],$$

$$\tau_{LL}=R-(2\theta_L-e_{LL})-\gamma\left[\frac{(e_{LL})^2}{2}+2(\theta_H-\theta_L)\,e_{HH}-2(\theta_H-\theta_L)^2\right],$$

$$e_{LL}=e_{LH}=e_{HL}=\frac{1}{\gamma},$$

and $e_{HH}=\frac{1}{\gamma}-\frac{2p}{(1-p)^2}(\theta_H-\theta_L).$

Note that because $e>0$, we must have $e_{HH}=e_{HH}-(\theta_H-\theta_L)>0$, and thus we obtain $\theta_H-\theta_L<(1-p)^2$.

3.4 Comparison

The principal's expected payoff under case 1 π^{*GI} is given by

$$\pi^{*GI}=R-2p\theta_L-2(1-p)\,\theta_H+\frac{1}{2}.$$

The principal's payoff under case 2 π^{*GO} is given by

$$\pi^{*GO} = R - 2\theta_H + \frac{1}{2} + \frac{p(1-p^2)}{(1-p)^2}(\theta_H - \theta_L)^2.$$

The principal's payoff under case 3 π^{*FI} is given by

$$\pi^{*FI} = R - 2\theta_H + \frac{1}{2}$$

The principal's payoff under case 4 π^{*FO} is given by

$$\pi^{*FO} = R - 2\theta_H + \frac{1}{2} + \frac{p(1-p^2)}{(1-p)^2}(\theta_H - \theta_L)^2.$$

Thus, we have the following result.

Proposition 3:

$$\pi^{*FI} < \pi^{*GO} = \pi^{*FO} < \pi^{*GI}.$$

Proof:

Comparing the principal's payoffs, we have

$$\pi^{*GO} - \pi^{*FI} = \frac{p(1-p^2)}{(1-p)^2}(\theta_H - \theta_L)^2 > 0$$

$$\text{and } \pi^{*GI} - \pi^{*FI} = 2p(\theta_H - \theta_L) > 0.$$

Also, because $\theta_H - \theta_L < \frac{(1-p)^2}{p^2+1}$, we have

$$\pi^{*GI} - \pi^{*GO} = p(\theta_H - \theta_L)\left[2 - \frac{p(1+p^2)}{(1-p)^2}(\theta_H - \theta_L)\right]$$

$$> p(\theta_H - \theta_L)(2-p) > 0.$$

3.5 Summary

We summarize the above results in Tables 1 and 2. The principal faces a decentralized organization or a fully consolidated organization. We have

$$\Pi^{FI} < \Pi^{GO} = \Pi^{FO} < \Pi^{GI}$$

$$\text{and } \pi^{*FI} < \pi^{*GO} = \pi^{*FO} < \pi^{*GI}.$$

Therefore, we obtain the following proposition.

Proposition 4: If the principal is subject to a decentralized contract with two agents or to an integrated contract with a single agent, he selects to be a residual claimant and chooses input monitoring. Regardless of the choice of residual claimancy, cost monitoring results in an intermediate payoff for the principal.

Table 1 Decentralization

Case	Principal's payoff
1	$\Pi^{GI} = R - 2p\theta_L - 2(1-p)\theta_H + 1$
2	$\Pi^{GO} = R - 2\theta_H + 1 + \frac{p}{1-p}(\theta_H - \theta_L)^2$
3	$\Pi^{FI} = R - 2\theta_H + 1$
4	$\Pi^{FO} = R - 2\theta_H + 1 + \frac{p}{1-p}(\theta_H - \theta_L)^2$

Table 2 Full Consolidation

Case	Principal's payoff
1	$\pi^{*GI} = R - 2p\theta_L - 2(1-p)\theta_H + \frac{1}{2}$
2	$\pi^{*GO} = R - 2\theta_H + \frac{1}{2} + \frac{p(1+p^2)}{(1-p)^2}(\theta_H - \theta_L)^2$
3	$\pi^{*FI} = R - 2\theta_H + \frac{1}{2}$
4	$\pi^{*FO} = R - 2\theta_H + \frac{1}{2} + \frac{p(1+p^2)}{(1-p)^2}(\theta_H - \theta_L)^2$

4 Optimal Organization Structure

In this section, we examine optimal organization structures. First, we assume that a monitoring instrument is determined exogenously. Because $\theta_H - \theta_L < \frac{(1-p)^2}{1+p^2}$, we have

$$\begin{aligned} \Pi^{GO} - \pi^{*GO} &= \frac{1}{2} - \frac{p^2(1+p)}{(1-p)^2}(\theta_H - \theta_L)^2 \\ &> \frac{1}{2} - \frac{p^2(1+p)(1-p)^2}{(1+p^2)^2} > 0 \\ \text{and } \; \pi^{*GO} &= \pi^{*FO} < \Pi^{GO} = \Pi^{FO}. \end{aligned}$$

Therefore, we conclude

$$\pi^{*GO} = \pi^{*FO} < \Pi^{GO} = \Pi^{FO}.$$

Hence, we obtain the following proposition.

Proposition 5: If cost monitoring is chosen, irrespective of residual claimancy, then the principal prefers the consolidated organization to the decentralized organization.

When the principal implements input monitoring, we obtain

$$\begin{aligned} \Pi^{GI} - \pi^{*GI} &= \frac{1}{2} > 0, \\ \Pi^{FI} - \pi^{*FI} &= \frac{1}{2} > 0, \\ \pi^{*GI} &< \Pi^{GI}, \\ \text{and } \; \pi^{*FI} &< \Pi^{FI}. \end{aligned}$$

Because $\theta_H - \theta_L < \frac{(1-p)^2}{1+p^2}$, we also have

$$\Pi^{FI} - \pi^{*GI} = \frac{1}{2} - 2p(\theta_H - \theta_L)$$
$$> \frac{-4p^3 + 9p^2 - 4p + 1}{2(p^2+1)} > 0$$

and $\pi^{*GI} < \Pi^{FI}$.

We have

$$\pi^{*FI} < \pi^{*GI} < \Pi^{FI} < \Pi^{GI},$$

and thus, we obtain the following proposition.

Proposition 6: If input monitoring is chosen, the principal prefers to be a residual claimant under the decentralized structure.

Next, we assume that residual claimancy is exogenously determined. Since $\theta_H - \theta_L < \frac{(1-p)^2}{1+p^2}$ and $0 < \frac{2p(1-p)^2}{(1+p)^2} < \frac{1}{2}$, we have

$$\Pi^{GO} - \pi^{*GI} = \frac{1}{2} + \frac{p}{1-p}(\theta_H - \theta_L)^2 - 2p(\theta_H - \theta_L)$$
$$> \frac{1}{2} + \frac{p}{1-p}(\theta_H - \theta_L)^2 - \frac{2p(1-p)^2}{1+p^2} > 0$$

and $\pi^{*GI} < \Pi^{GO}$.

Hence, when the principal is a residual claimant, we have

$$\pi^{*GO} < \pi^{*GI} < \Pi^{GO} < \Pi^{GI}.$$

Thus, we have the following proposition.

Proposition 7: If the principal is a residual claimant, then input monitoring under the decentralized organization yields the highest payoff.

Since $(\theta_H - \theta_L)^2 < \frac{(1-p)^4}{(1-p^2)^2}$ and $0 < \frac{p(1-p)^2}{1+p^2} < \frac{1}{2}$, we have

$$\Pi^{FI} - \pi^{*FO} = \frac{1}{2} - \frac{p(1+p^2)}{(1-p)^2}(\theta_H - \theta_L)^2$$
$$> \frac{1}{2} - \frac{p(1-p^2)}{(1+p)^2} > 0$$

and $\pi^{*FO} < \Pi^{FI}$.

Hence, when the agent is a residual claimant, we have

$$\pi^{*FI} < \pi^{*FO} < \Pi^{FO} < \Pi^{FO}.$$

Thus, we obtain the following proposition.

Proposition 8: If the agent is a residual claimant, then cost monitoring under the decentralized organization yields the highest payoff for the principal.

5 Conclusion

In this paper we have examined optimal contracts under two organizational structures, incorporating adverse selection and moral hazard. Because contributions to the literature on regulation include multiple agents with private information, we have characterized optimal contracts according to the following choices: organizational structures, residual claimancy, and monitoring instruments. We have shown that under a decentralized structure, the principal prefers to be a residual claimant, choosing input monitoring to obtain the highest payoff. When the principal grants residual claimancy to agents and implements input monitoring, he obtains the lowest payoff. The principal obtains intermediate payoffs under cost monitoring irrespective of the choice of residual claimancy. We also have shown that in a consolidated organization, when the principal chooses to be a residual claimant and to implement input monitoring, he obtains the highest payoff. When implementing cost monitoring, the principal chooses a consolidated organization and obtains a higher payoff than that under the decentralized organization. The results in this paper suggest some policy recommendations for regulating industries such as toll expressways. Thus, to reform the Japan Highway Public Corporation (noted in Introduction), we conclude that by implementing cost monitoring, the principal would be better off under a consolidated organization than under the decentralized organization.

Appendix

Proof of Lemma 1

Because the principal can monitor inputs, he can choose the optimal effort for each agent.

Thus, the transfers are given by

$$t^A_{Hj} = \gamma \frac{(e^A_{Hj})^2}{2},$$

$$t^B_{iH} = \gamma \frac{(e^B_{iH})^2}{2},$$

$$p_{LL} t^A_{LL} + p_{LH} t^A_{LH} = p_{LL} \gamma \frac{(e^A_{LL})^2}{2} + p_{LH} \gamma \frac{(e^A_{LL})^2}{2},$$

$$\text{and } \; p_{LL} t^B_{LL} + p_{HL} t^B_{HL} = p_{LL} \gamma \frac{(e^B_{LL})^2}{2} + p_{HL} \gamma \frac{(e^B_{HL})^2}{2}.$$

Substituting these transfers into the principal's payoffs and taking the first-order conditions with respect to e_{ij}^{A} and e_{ij}^{B}, we obtain

$$e_{ij}^{A} = e_{ij}^{B} = \frac{1}{\gamma} = e^{FB}, \quad i, j = L, H,$$

where e^{FB} denotes the first best effort level.

Proof of Lemma 2

The transfers are given by

$$t_{Hj}^{A} = \gamma \frac{(e_{Hj}^{A})^2}{2},$$
$$t_{iH}^{B} = \gamma \frac{(e_{iH}^{B})^2}{2},$$

$$\begin{aligned} p_{LL}t_{LL}^{A} + p_{LH}t_{LH}^{A} = p_{LL} & \left[\frac{(e_{LL}^{A})^2}{2} + (\theta_H - \theta_L)\, e_{HL}^{A} - \frac{(\theta_H - \theta_L)^2}{2} \right] \\ + p_{LH} & \left[\frac{(e_{LH}^{A})^2}{2} + (\theta_H - \theta_L)\, e_{HH}^{A} - \frac{(\theta_H - \theta_L)^2}{2} \right], \end{aligned}$$

$$\begin{aligned} \text{and } p_{LL}t_{LL}^{B} + p_{HL}t_{HL}^{B} = p_{LL} & \left[\frac{(e_{LL}^{B})^2}{2} + (\theta_H - \theta_L)\, e_{Hj}^{B} - \frac{(\theta_H - \theta_L)^2}{2} \right] \\ + p_{HL} & \left[\frac{(e_{HL}^{B})^2}{2} + (\theta_H - \theta_L)\, e_{HH}^{B} - \frac{(\theta_H - \theta_L)^2}{2} \right]. \end{aligned}$$

Substituting these transfers into the principal's payoff and taking the first order conditions with respect to e_{ij}^{A} and e_{ij}^{B}, we have

$$e_{LL}^{A} = e_{LH}^{A} = e_{LL}^{B} = e_{HL}^{B} = \frac{1}{\gamma}$$
$$\text{and } e_{HL}^{A} = e_{LH}^{B} = e_{HH}^{A} = e_{HH}^{B} = \frac{1}{\gamma} - \frac{p}{1-p}(\theta_H - \theta_L).$$

Proof of Lemma 3

The transfers are given by

$$\tau_{Hj}^{A} = \frac{R}{2} - (\theta_H - e_{Hj}^{A}) - \frac{(e_{Hj}^{A})^2}{2},$$
$$\tau_{iH}^{B} = \frac{R}{2} - (\theta_H - e_{iH}^{B}) - \frac{(e_{iH}^{B})^2}{2},$$

$$p_{LL}\tau_{LL} + p_{LH}\tau_{LH} = p_{LL}\left[\frac{R}{2} - \theta_H + e^A_{LL} - \gamma\frac{(e^A_{LL})^2}{2}\right] + p_{LH}\left[\frac{R}{2} - \theta_H + e^A_{LH} - \frac{(e^A_{HL})^2}{2}\right],$$

$$\text{and } p_{LL}\tau_{LL} + p_{HL}\tau_{HL} = p_{LL}\left[\frac{R}{2} - \theta_H + e^B_{LL} - \gamma\frac{(e^B_{LL})^2}{2}\right] + p_{HL}\left[\frac{R}{2} - \theta_H + e^B_{HL} - \frac{(e^B_{HL})^2}{2}\right].$$

Inserting these transfers into the principal's payoff and taking the first-order condition with respect to e^A_{ij} and e^B_{ij} , we have

$$e^A_{ij} = e^B_{ij} = e^{FB} = \frac{1}{\gamma}, \quad i, j = L, H.$$

Proof of Lemma 4

The transfers are given by

$$\pi^A_{Hj} = \frac{R}{2} - (\theta_H - e^A_{Hj}) - \gamma\frac{(e^A_{Hj})^2}{2}$$

$$\pi^B_{iH} = \frac{R}{2} - (\theta_H - e^B_{iH}) - \gamma\frac{(e^B_{iH})^2}{2},$$

$$p_{LL}\tau_{LL} + p_{LH}\tau_{LH} = p_{LL}\left[\frac{R}{2} - \theta_L + e^A_{LL} - \gamma\frac{(e^A_{LL})^2}{2} - \gamma(\theta_H - \theta_L)e^A_{HL} + \gamma\frac{(\theta_H - \theta_L)^2}{2}\right]$$
$$+ p_{LH}\left[\frac{R}{2} - \theta_L + e^A_{LH} - \gamma\frac{(e^A_{LH})^2}{2} - \gamma(\theta_H - \theta_L)e^A_{HH} + \gamma\frac{(\theta_H - \theta_L)^2}{2}\right],$$

$$\text{and } p_{LL}\tau^B_{LL} + p_{HL}\tau^B_{HL} = p_{LL}\left[\frac{R}{2} - \theta_L + e^B_{LL} - \gamma\frac{(e^B_{LL})^2}{2} - \gamma(\theta_H - \theta_L)e^B_{LH} + \gamma\frac{(\theta_H - \theta_L)^2}{2}\right]$$
$$+ p_{LH}\left[\frac{R}{2} - \theta_L + e^B_{HL} - \gamma\frac{(e^B_{HL})^2}{2} - \gamma(\theta_H - \theta_L)e^B_{HH} + \gamma\frac{(\theta_H - \theta_L)^2}{2}\right],$$

We insert these transfers into the principal's payoff. From the first-order conditions with respect to e^A_{ij} and e^B_{ij}, we obtain

$$e^A_{LL} = e^A_{LH} = e^B_{LL} = e^B_{HL} = \frac{1}{\gamma}$$
$$\text{and } e^A_{HL} = e^B_{LH} = e^A_{HH} = e^B_{HH} = \frac{1}{\gamma} - \frac{p}{1-p}(\theta_H - \theta_L).$$

Proof of Lemma 5

The transfer is given by

$$t_{ij} = \gamma\frac{(e_{ij})^2}{2}.$$

Inserting these transfers into the principal's payoffs and taking the first order conditions, we have

$$e_{ij} = \frac{1}{\gamma}.$$

Proof of Lemma 6

$$t_{HH} = \gamma \frac{(e_{HH})^2}{2},$$
$$t_{LH} = \gamma \left[\frac{(e_{LH})^2}{2} + (\theta_H - \theta_L)\, e_{HH} - \frac{(\theta_H - \theta_L)^2}{2}\right],$$
$$t_{HL} = \gamma \left[\frac{(e_{HL})^2}{2} + (\theta_H - \theta_L)\, e_{HH} - \frac{(\theta_H - \theta_L)^2}{2}\right],$$

When the last incentive compatibility constraint is binding, transfers t_{LH}, t_{HL} and t_{HH} are identical and t_{LL} is given by

$$t_{LL} = \gamma \left[\frac{(e_{LL})^2}{2} + 2(\theta_H - \theta_L)\, e_{HH} - 2(\theta_H - \theta_L)^2\right].$$

Inserting these transfers into the principal's payoff and taking the first-order condition with respect to e_{ij}, we obtain

$$e_{LL} = e_{LH} = e_{HL} = \frac{1}{\gamma}$$
$$\text{and } \; e_{HH} = \frac{1}{\gamma} - \frac{2p}{(1-p)^2}(\theta_H - \theta_L).$$

Proof of Lemma 7

The transfers are given by

$$\tau_{HH} = R - (2\theta_H - e_{HH}) - \gamma \frac{(e_{HH})^2}{2},$$
$$\tau_{HL} = R - (2\theta_H - e_{HL}) - \gamma \frac{(e_{HL})^2}{2},$$
$$\tau_{LH} = R - (2\theta_H - e_{LH}) - \gamma \frac{(e_{LH})^2}{2},$$

$$\text{and } \; \tau_{LL} = R - (2\theta_H - e_{LL}) - \gamma \frac{(e_{LL})^2}{2}.$$

Substituting these transfers to the principal's payoff and taking the first-order condition with respect to e_{ij}, we obtain

$$e_{ij} = \frac{1}{\gamma}.$$

Proof of Lemma 8

$$\tau_{HH} = R - (2\theta_H - e_{HH}) - \gamma \frac{(e_{HH})^2}{2},$$

$$\tau_{LH} = R - (\theta_L + \theta_H - e_{LH}) - \gamma \left[\frac{(e_{LH})^2}{2} + (\theta_H - \theta_L)\, e_{HH} - \frac{(\theta_H - \theta_L)^2}{2} \right],$$

$$\tau_{HL} = R - (\theta_H + \theta_L - e_{HL}) - \gamma \left[\frac{(e_{HL})^2}{2} + (\theta_H - \theta_L)\, e_{HH} - \frac{(\theta_H - \theta_L)^2}{2} \right],$$

When the last incentive compatibility constraint is binding, transfers τ_{LH}, τ_{HL} and τ_{HH} are identical and τ_{LL} is given by

$$\tau_{LL} = R - (2\theta_L - e_{LL}) - \gamma \left[\frac{(e_{LL})^2}{2} + 2(\theta_H - \theta_L)\, e_{HH} - 2(\theta_H - \theta_L)^2 \right].$$

Inserting these transfers into the principal's payoff and taking the first-order conditions with respect to e_{ij}, we have

$$e_{LL} = e_{LH} = e_{HL} = \frac{1}{\gamma}$$

and $e_{HH} = \dfrac{1}{\gamma} - \dfrac{2p}{(1-p)^2}(\theta_H - \theta_L)$.

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