Payment Plan for the Delegation of One or Two Inspection Agencies

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***Abstract*: This paper provides the framework for a payment plan based on inspection results in the delegation of inspection agencies. The paper deals with two cases—that in which one inspector checks the quality of the inspection object (e.g., a design drawing of building) and that in which two inspectors check it simultaneously. The paper points out the applicability of a penalty only in the framework with two inspectors. In addition, it is shown that an appropriate bonus and penalty system based on inspection results can resolve moral hazard and adverse selection problems, and that the framework with two inspectors is superior to that with one if both the upper bound of penalty and social loss, which occurs when the object that does not meet the requisite standards passes an inspection, are relatively large.**

***Index Terms*: delegation of inspection, payment plan, institutional design, bonus and penalty**

I. INTRODUCTION

This paper provides a framework of a payment plan for inspectors who are delegated to inspect the quality of inspection objects (e.g., system maintenance, food safety, accounting audit, quake-resistance of building, etc). Difficulties related to inspectors who overlook the defects in certain objects have been witnessed in various fields. For example, the Enron-Anderson scandal in 2001 had a great impact on the credibility of auditing reports. Likewise, the scandal related to the falsification of the quakeproof date on condominiums and hotels was a serious social concern in Japan in 2006. The building inspectors overlooked the defects in the design drawings, and as a result, approximately a hundred condominiums and hotels that did not meet the Building Standard Law were constructed.

Undoubtedly, if a company reports its business performance honestly, accounting auditors do not need to check the business performance. As a result, investors would be able to trust the report of their business performance provided by companies. Similarly, if a designer creates a design drawing that meets the requisite standards, inspectors would not need to conduct rigorous inspections. However, a company may manipulate accounting information. A designer may intentionally create a design drawing that does not meet standards, and a building contractor may build a condominium at a lower cost. Therefore, the main role of inspectors is to verify the quality of objects according to requisite standards.

However, even inspectors may indulge in opportunistic actions, for example, simplifying a necessary procedure in an inspection, in order to seek private profits. Then, it may be stated that inspectors are not playing the role that they are originally supposed to. Moreover, even worse, if the inspections are doubtful, it is meaningless to establish a system to inspect the inspectors themselves because the system also may be doubtful. As a result, an infinite regression problem related to inspection may occur. This paper provides a framework for a payment plan based on inspection results in the delegation of one or two inspectors for trustworthy inspection systems, and analyzes the difference between the two frameworks.

This paper is organized as follows. In section 2, we present the framework of our analysis and the viewpoint provided in past literatures. In section 3, we formulate the basic model in which inspection is conducted by one inspector in two cases—one where the ability of the inspector is homogeneous and the other where it is heterogeneous. It is shown that a bonus system of identifying the defect can be effective in trustworthy inspections. In section 4, we extend the model in which two inspectors who check the same inspection object simultaneously. It is indicated that the bonus and penalty system can be effective for trustworthy inspections. In section 5, we compare the framework of one inspector with that of two, and indicate which framework is socially effective in regard to the social cost. Last, in section 6, the analysis is concluded, and the topics for further research are discussed.

II. FRAMEWORK

One approach for overcoming the problem related to inspectors is to make inspectors responsible in cases where a social loss occurs as a consequence of overlooking defects [1]–[5]. However, this method of overcoming the problem is not always effective. This is because the effectiveness of this approach depends on how often the validity of inspection results is revealed in public [6]. In the case of inspection of the quality of design drawings, building inspectors are rarely exposed for their negligent inspections due to not only the poor ability of a building client to observe the quality of buildings but also the low frequency of earthquakes that may expose their negligent inspections in the event of building collapses. These facts imply that inspectors have few opportunities to assume responsibility of their negligent inspections. Therefore, short-sighted inspectors may not be worried with regard to ex-post responsibility.

Reputation mechanism is also regarded as a way to provide appropriate incentives with inspectors, particularly, in the context of accounting auditing [7]–[8]. If an auditor overlooks an accounting manipulation of a company and the manipulation is subsequently exposed publicly, the auditor loses his reputation since such a revelation makes it appear that the auditor's report of other companies may also not be reliable. Consequently, auditors attempt to report more accurate information regarding the business performance of companies. Thus, they seek to acquire a good reputation in order to ensure future earnings. However, this reputation mechanism may not be effective for the same reason as the ex-post responsibility approach. When the validity of audit reports is rarely revealed publicly, the reputation mechanism is not effective in creating a trustworthy inspection system. This implies the necessity of a different institutional design for conducting trustworthy inspections.

Another approach for tackling the problems related to inspectors focuses on inspection results. A characteristic of problems related to inspectors is that they may pass the inspection object without exerting adequate effort in the inspection. It is usually difficult to indicate the defect of an object without exerting much effort in the inspection. If an inspector identifies a defect and declares the design as inappropriate, it may be evident that he has conducted a stringent inspection. Therefore, inspection results can form a basis for judging whether or not a stringent inspection has been conducted. This approach has been analyzed in past literatures using the Contract Theory [9]–[11]. In these models, a principal prevents inspectors from taking an opportunistic action (moral hazard, coalition) by imposing the condition that it is more advantageous for an inspector to report truthful information. In other words, a principal provides an additional reward if an inspector reports effective information on a principal's payoff. This research adopts this approach to solve the inspectors' problem. In addition, we extend the framework, which was discussed in the past literatures, where one inspector checks the quality of inspection objects to the one where two inspectors simultaneously check the quality of inspection objects. In the framework with two inspectors, each inspector's payment is based on two inspection results. Then, there could be a situation that one inspector identifies the defect in an inspection object but the other does not. In such a situation, the fact that the second inspector has not been able to identify the defect is revealed publicly. The penalty mechanism is applicable at the inspection stage only after such a public revelation. This paper includes both frameworks—inspection by one and two inspectors—and analyzes when one framework must be selected over the other. In the following section, we analyze the frameworks in the context of inspection related to the quality of design drawings in the construction market; however, this framework is applicable in other areas as well.

III. THE MODEL WITH ONE BUILDING INSPECTOR

A. Preliminary Settings

This model includes the planner (e.g., municipality) and the building inspector. The role of the planner is to determine the payment plan for the building inspector. The building inspector has two action choices, one is to exert an effort in inspection $(e=1)$ and the other is not to exert an effort $(e=0)$. Let $\psi(e)$ be his cost function in inspection based on the effort level. For the sake of simplicity, we specify $\psi(1)=\psi$ (>0) and $\psi(0)=0$. Further, it is assumed that the effort level e is private information regarding the building inspector and the planner cannot observe it. The quality of the design drawings is assumed to be of two types; $S \in \{G, B\}$. One type, G, is a design drawing that meets the standards, and the other type, B, does not. Let ε be the proportion of design drawings that does not satisfy the standards. The planner can control this proportion by imposing a penalty on the building designers; however, we do not consider this here. The inspection results reported by the building inspector after his inspection are also assumed to be of two types, $m \in \{g, b\}$. g is the inspection result that the inspected design drawing meets the requisite standards, and b is the opposite result. It is assumed that the inspection results reported by the building inspector are observable and verifiable by the planner. In addition, it is assumed that there are two types of information that the building inspector can obtain with regard to the quality of the design drawing, $i_s \in \{i_\phi, i_b\}$. i_b indicates verifiable information that the design drawing does not meet requisite standards, and i_ϕ does not include such evidence.

In the case of G, the building inspector always obtains i_ϕ regardless of whether or not he is exerting an effort. In the case of B, with effort, the building inspector can identify the defects in the design drawing; however, he is unable to identify all the design drawings that do not meet requisite standards. In the case of B, the building inspector can obtain i_b with probability p ($0<p<1$) by exerting an effort, and then he obtains i_ϕ with probability

$1-p$. This implies that the inspector may overlook a design drawing that does not meet the requisite standards despite exerting an effort in inspection with probability $1-p$. In the following analysis, p denotes the ability of the building inspector. Finally, if the building inspector decides not to exert an effort in inspection, he cannot always obtain information regarding the quality of the design drawing in both cases G and B. This case corresponds to the one in which the building inspector obtains i_ϕ.

When the building inspector reports b as an inspection result, he has to specify what contravenes the standards. In addition, if the building inspector reports b when the true quality of the design drawing is G, then the case would lead to a costly conflict between the building designer and inspector Therefore, it is assumed that he reports b only when the building inspector has i_b. On the other hand, it is assumed that the building inspector can report g regardless of whether he has i_b.

Let $R(m)$ be the payment of the building inspector that is based on the inspection result m; we specify $R(g)=v$ and $R(b)=w$.

B. One Homogeneous Inspector

In this section, the analysis considers that the inspection is conducted by one building inspector whose ability is homogeneous. It is assumed that the building inspector is risk-averse, and his payoff function $\pi(e)$ is assumed to be separable between money and effort,

$$\pi(e) = epu(w) + (1-ep)u(v) - \psi(e)\ , \tag{1}$$

where $u(\cdot)$ is his utility function in terms of money and is assumed to be increasing and concave ($u'(\cdot)\geq 0,\ u''(\cdot)\leq 0$). We will occasionally use the function $h=u^{-1}$, the inverse function of $u(\cdot)$, that is increasing and convex ($h'(\cdot)\geq 0$, $h''(\cdot)\geq 0$).

The decision-making problem of the building inspector is described as $max_{e\in\{0,1\}}\pi(e)$. Then, the incentive compatibility constraint that the building inspector decides to exert an effort in the inspection is described as

$$\pi(1)\geq \pi(0)\ . \tag{2}$$

In addition, the participatory constraint that the building inspector receives a nonnegative expected payoff per inspection is described as

$$\pi(1)\geq 0\ . \tag{3}$$

In addition, regardless of the proportion ε, the planner has to give a nonnegative payment to the building inspector who always exerts an effort. Therefore, the following constraints must be considered to be the cost compensation constraints:

$$u(v)\geq \psi\ , \tag{4}$$
$$u(w)\geq \psi\ . \tag{5}$$

In existing literature, such a constraint is known as the limited liability constraint; however, in this context, we call these constraints cost compensation constraints [12]. Then, the expected payment of the inspector per inspection, $g_1(v,w)$, is described as

$$\begin{aligned} g_1(v,w) &= (1-\varepsilon)v + \varepsilon pw + \varepsilon(1-p)v \\ &= (1-\varepsilon p)v + \varepsilon pw\ . \end{aligned} \tag{6}$$

The optimization problem for the planner is described as

$$[P1] \qquad \min_{v,w} g_1(v,w)$$
$$s.t. (2), (3), (4), and (5)$$

Solving $[P1]$, we obtain the optimal payment plan $(v_1^*, w_1^*) = \left(h(\psi), h(\psi+\psi/\varepsilon p)\right)$. This result indicates that when reporting g, the building inspector receives a minimum payoff, which is compensated for by the inspection cost. In addition, it is indicated that he receives a higher payoff when he reports b than when he reports g. In other words, it is shown that the bonus system in the case where the inspector identifies the design drawing as B prevents an inspector taking moral hazard action in inspection.

C. One Heterogeneous Inspector

In this section, the analysis considers that the inspection is conducted by one building inspector who is heterogeneous with respect to inspection ability p, which is distributed over $[\underline{p},\overline{p}]$ with the cumulative distribution function $F(p)$. Let us define $p_E=\int_{\underline{p}}^{\overline{p}} pdF(p)$ as the expectation of the abilities of the inspector.

An important viewpoint on inspection ability is whether or not the payoff the inspector receives can increase with his ability. If the building inspector who maximizes his payoff receives a fixed payment, he always decides not to exert an effort and reports g. Then, the building inspector does not have any incentive to improve his ability. This can lead to an adverse selection problem in terms of inspection ability.

If the planner observes the ability of building inspectors, it is possible to differentiate their payments according to ability. However, ability usually constitutes private information pertaining to each building inspector. This paper considers the ability improvement constraint—that the higher the ability of the building inspector, the higher is the payoff he receives. The constraint forms the necessary condition for the building inspectors to improve their abilities.

Let us define $\pi(e;p)=\pi(e)$ as the payoff function for the building inspector with the ability $p\in[\underline{p},\overline{p}]$. The ability improvement constraint is described as

$$\frac{\partial\pi(1;p)}{\partial p}\geq 0\ ,\ \forall p\in\left[\underline{p},\overline{p}\right]. \tag{7}$$

In addition, the incentive compatible constraint and the participatory constraint are described as

$$\pi(1;p)-\pi(0;p)\geq 0 \ \ ,\forall p\in\left[\underline{p},\overline{p}\right] \text{ and} \tag{8}$$

$$\pi(1;p)\geq 0 \ \ ,\forall p\in\left[\underline{p},\overline{p}\right], \tag{9}$$

respectively. Furthermore, the cost compensation constraints in (4) and (5) should also be considered in the case of one heterogeneous building inspector. Let us define $g_2(v,w)=E_p[g_1(v,w)]$ as the expected payment per inspection for the heterogeneous building inspector, where $E_p[\cdot]$ is the expectation operator with respect to p. The program for the planner is described as

$$[P2] \qquad \min_{v,w} g_2(v,w)$$
$$s.t. (4),(5),(7),(8) and (9)$$

Solving $[P2]$, we obtain the optimal payment plan $(v_2^*,w_2^*)=\ (h(\psi),h(\psi+\psi/\varepsilon\underline{p}))$. This result indicates that when he reports g, the building inspector should receive the minimum payment that compensates for the inspection cost. Further, when he reports b, he should receive a higher payoff than when he reports g. Then, the incentive compatible constraint for the building inspector with the minimum ability $\underline{p}$ is binding.

As a result, in the framework with one inspector, the bonus system in the case where the building inspector identifies the design drawing as B is effective in solving both the moral hazard and the adverse selection problems.

IV. THE MODEL WITH TWO INSPECTORS

A. Two Homogeneous Inspectors

This section considers the model in which there are two building inspectors who simultaneously inspect the same design drawing. Then, if one building inspector identifies the defect of the design drawing but the other does not, then the case results in a public revelation that the latter has overlooked the defectiveness of the design drawing. Therefore, a penalty regulation can be applied to the building inspector who failed to identify the defect of the design drawing. The applicability of the penalty mechanism is the main feature in the framework of inspection by two inspectors.

There are two independent building inspectors, $i\in\{1,2\}$, who are homogeneous with respect to their abilities p. The coalition between two building inspectors is not considered here. Let us define $e_i\in\{1,0\}$ and $m_i\in\{g,b\}$ as the effort level and inspection result, respectively, for each i. Let $R_i(m_1,m_2)$ be the payment to building inspector i, which is based on two inspection results. If the two building inspectors report the same result g or b, the planner cannot differentiate their payments; therefore we specify $R_i(g,g)=v$ and $R_i(b,b)=w$. On the other hand, if one inspector reports g and the other reports b, their payments can be differentiated. We specify $R_1(g,b)=y$, $R_2(g,b)=x$, $R_1(b,g)=x$, and $R_2(b,g)=y$. The payment plan based on both inspection results, $R_i(m_1,m_2)$, is presented in Table I.

TABLE I
PAYMENT PLAN BASED ON INSPECTION RESULTS

(m_1,m_2)	(R_1,R_2)
(g,g)	(v,v)
(g,b)	(y,x)
(b,g)	(x,y)
(b,b)	(w,w)

TABLE II
PAYOFF MATRIX FOR TWO INSPECTORS

	$e_2=1$	$e_2=0$
$e_1=1$	$(\pi(1,1),\pi(1,1))$	$(\pi(1,0),\pi(0,1))$
$e_1=0$	$(\pi(0,1),\pi(1,0))$	$(\pi(0,0),\pi(0,0))$

Let $\pi_i(e_1,e_2)$ be the payoff function of building inspector $i\in\{1,2\}$, which is individually described as $\pi_1(e_1,e_2)$ $=\varepsilon\{e_1e_2p^2u(w)+$ $e_1p(1-e_2p)u(x)+e_2p(1-e_1p)u(y)$ $+(1-e_2p)$ $(1-e_1p)u(v)\}+(1-\varepsilon)u(v)-\psi(e_1)$ and $\pi_2(e_1,e_2)=$ $\varepsilon\{e_1e_2p^2u(w)$ $+e_2p(1-e_1p)u(x)+e_1p(1-e_2p)u(y)+(1-e_1p)(1-e_2p)u(v)\}+$ $(1-\varepsilon)u(v)-\psi(e_2)$. Let us define $\pi(e_1,e_2)=\pi_1(e_1,e_2)$. Taking into consideration the symmetry of the payoff functions, the payoff matrix can be written as in Table II. For the condition that both the building inspectors exert efforts in inspection, a Nash equilibrium condition is considered. The condition that $(e_1^*,e_2^*)=(1,1)$ is the only Nash equilibrium is given by

$$\pi(1,1)-\pi(0,1)\geq\delta(>0) \text{ and} \tag{11}$$

$$\pi(1,0)-\pi(0,0)\geq\delta(>0), \tag{12}$$

with δ given exogenously. In addition to the case of one building inspector, a participatory constraint should also be considered, which is described as

$$\pi(1,1)\geq 0. \tag{13}$$

In addition, the cost compensation constraints—(4) and (5)—should also be considered. Under conditions (4) and (5), when both the building inspectors report the same inspection result, the inspection payment cannot be differentiated; however, their inspection costs are compensated for. In addition, the cost compensation constraint regarding x should be taken into consideration; it is described as

$$u(x)\geq\psi. \tag{14}$$

A building inspector receives x in the case where he identifies the defect but the other does not identify it, and hence, x plays a role in the bonus. On the other hand, a building inspector receives y in the case where he overlooks the defect but the other identifies it, and hence y plays a role in the penalty. Since a penalty that is rather strict is not feasible, the maximum penalty is restricted. The maximum penalty constraint with regard to y is given by

$$u(y) \geq -l \, (l > 0) \, , \tag{15}$$

with l given exogenously. Let $g_3(v,w,x,y)$ be the expected payment per inspection, which is described as

$$\begin{aligned} g_3(v,w,x,y) &= (1-\varepsilon)v + \varepsilon(1-p)^2 v + \varepsilon p^2 w \\ &\quad + \varepsilon p(1-p)x + \varepsilon p(1-p)y \\ &= (1-2\varepsilon p + \varepsilon p^2)v + \varepsilon p^2 w + \varepsilon p(1-p)(x+y). \end{aligned} \tag{16}$$

Then, the program for the planner is described as follows:

$$[P3] \qquad \min_{v,w,x,y} 2 \times g_3(v,w,x,y)$$
$$s.t. (4), (5), (11), (12), (13), (14), and (15)$$

Solving $[P3]$, the optimal payment plan $(v_3^*, w_3^*, x_3^*, y_3^*)$ is described as follows.

- For $\dfrac{\psi+\delta}{\varepsilon p} - \psi \geq l$,

$$(v_3^*, w_3^*, x_3^*, y_3^*) = \left(h(\psi), h(\frac{\psi+\delta}{\varepsilon p} - l), h(\psi + \frac{\psi+\delta}{\varepsilon p}), h(-l) \right)$$

- For $l \geq \dfrac{\psi+\delta}{\varepsilon p} - \psi$,

$$(v_3^*, w_3^*, x_3^*, y_3^*) = \left(h(\psi), h(\psi), h(\psi + \frac{\psi+\delta}{\varepsilon p}), h(\psi - \frac{\psi+\delta}{\varepsilon p}) \right).$$

It is indicated that the appropriate bonus and penalty can resolve the moral hazard problem for the building inspectors. To be more precise, it is shown that the payment v that is received the building inspectors when both of them report g should be the minimum payment that compensates for the inspection cost. In addition, it is indicated that the penalty constraint affects the payment w that is received by the building inspectors when both of them identify the defect, and the payment y that is received by the building inspector who overlooks the defect when either building inspector identifies the defect. In the case where a large penalty is not feasible, the moral hazard problem can be dealt with by increasing the payment w . Furthermore, it is shown that the cost compensation constraint for x is not binding at any l . In other words, when one building inspector identifies the defect and the other does not, the planner should give the bonus to the building inspector who identifies it.

B. Two Heterogeneous Inspectors

In this section we deal with the model in which two building inspectors who are heterogeneous in their abilities carry out an inspection of a design drawing. Let p_i be the ability of the building inspector i , which is distributed over $[\underline{p}, \overline{p}]$ with the cumulative distribution function $F_i(p_i) = F(p_i)$. Let $\pi_1(e_1, e_2;\ p_1, p_2)$ be the payoff function, which is described as $\pi_1(e_1,e_2; p_1,p_2) = \varepsilon\{e_1 e_2 p_1 p_2 u(w) + (1-e_1 p_1)e_2 p_2 u(y) + (1-e_2 p_2)e_1 p_1 u(x) + (1-e_1 p_1)(1-e_2 p_2) u(v)\} + (1-\varepsilon)u(v) - \psi(e_1)$ and $\pi_2(e_1,e_2; p_1,p_2) = \varepsilon\{e_1 e_2 p_1 p_2 u(w) + (1-e_1 p_1)e_2 p_2 u(x) + (1-e_2 p_2)e_1 p_1 u(y) + (1-e_1 p_1)(1-e_2 p_2) u(v)\} + (1-\varepsilon)u(v) - \psi(e_2)$, respectively. In addition, it is assumed that the inspector i knows his ability p_i but he does not know the other inspector's ability p_j ($j \neq i$, $j \in \{1,2\}$).

Let $E_{p_j}[\pi(e_1,e_2; p_i)]$ be the expected payoff function of building inspector i with ability p_i ; it is individually described as $E_{p_2}[\pi(e_1,e_2; p_1)] = \varepsilon\{e_1 e_2 p_1 p_E u(w) + e_1 p_1 (1-e_2 p_E) u(x) + e_2 p_E (1-e_1 p_1) u(y) + (1-e_1 p_1)(1-e_2 p_E) u(v)\} + (1-\varepsilon)u(v) - \psi(e_1)$ and $E_{p1}[\pi(e_1,e_2; p_2)] = \varepsilon\{e_1 e_2 p_E p_2 u(w) + e_2 p_2 (1-e_1 p_E) u(x) + e_1 p_E (1-e_2 p_2) u(y) + (1-e_2 p_2)(1-e_1 p_E) u(v)\} + (1-\varepsilon) u(v) - \psi(e_2)$. Let us define $E[\pi(e_1,e_2; p)] = \varepsilon\{e_1 e_2 p p_E u(w) u(w) + e_1 p(1-e_2 p_E) u(x) + e_2 p_E (1-e_1 p) u(y) + (1-e_1 p)(1-e_2 p_E) u(v)\} + (1-\varepsilon)u(v) - \psi(e_1)$. Taking into consideration the symmetry of the expected payoff functions, the participatory constraint can be described as

$$E\left[\pi(1,1;p)\right] \geq 0 \ \ , \forall p \in \left[\underline{p}, \overline{p}\right]. \tag{17}$$

The Bayesian-Nash equilibrium condition is considered as that where both inspectors exert efforts in the inspection, and is described as

$$E\left[\pi(1,1;p)\right] - E\left[\pi(1,0;p)\right] \geq \delta(>0) \, , \forall p \in \left[\underline{p}, \overline{p}\right] \text{ and} \tag{18}$$

$$E\left[\pi(1,0;p)\right] - E\left[\pi(0,0;p)\right] \geq \delta(>0) \, , \forall p \in \left[\underline{p}, \overline{p}\right], \tag{19}$$

with δ given exogenously. In addition, the ability improvement constraint is also taken into consideration, which is described as

$$\frac{\partial E\left[\pi(1,1;p)\right]}{\partial p} \geq 0 \, , \ \forall p \in \left[\underline{p}, \overline{p}\right]. \tag{20}$$

Let $g_4(v,w,x,y)$ be the expected payment per inspection, which is described as

$$\begin{aligned} g_4(v,w,x,y) &= (1-2\varepsilon p_E + \varepsilon p_E^2)v \\ &\quad + \varepsilon p_E^2 w + \varepsilon p_E(1-p_E)(x+y) \quad . \end{aligned} \tag{21}$$

The planner should take account of the constraints for each payment v , w , x and y as well as the two homogeneous case. Then, the problem for the planner can be expressed as follows:

$$[P4] \qquad \min_{v,w,x,y} 2 \times g_4(v,w,x,y)$$
$$s.t. (4), (5), (14), (15), (17), (18), (19), and (20)$$

Solving $[P4]$, we obtain the following optimal payment plan $(v_4^*, w_4^*, x_4^*, y_4^*)$.

- For $\frac{\psi+\delta}{\varepsilon p_E} - \psi \ge l$,

$$(v_4^*, w_4^*, x_4^*, y_4^*) = \left(h(\psi), h(\frac{\psi+\delta}{\varepsilon \underline{p}} - l), h(\psi + \frac{\psi+\delta}{\varepsilon \underline{p}}), h(-l) \right).$$

- For $l \ge \frac{\psi+\delta}{\varepsilon \underline{p}} - \psi$, $(v_4^*, w_4^*, x_4^*, y_4^*)$

$$= \left(h(\psi), h(\frac{(\psi+\delta)(p_E - \underline{p})}{\varepsilon p_E \underline{p}} + \psi), h(\psi + \frac{\psi+\delta}{\varepsilon \underline{p}}), h(\psi - \frac{\psi+\delta}{\varepsilon p_E}) \right).$$

It is shown that the bonus and penalty system can resolve not only the moral hazard problem but also adverse selection problem. To be more precise, it is indicated that even if a large penalty is feasible, the cost compensation constraint for w is not binding in the case of two heterogeneous building inspectors. In other words, when both building inspectors identify the defect, the planner should offer a payment that exceeds the minimum cost. This is the main difference between the homogeneous and heterogeneous cases.

V. COMPARISON BETWEEN THE FRAMEWORK WITH ONE AND TWO INSPECTORS

A. Formulation of Total Social Cost

As analyzed above, we presented the structure of the payment plan in both cases—one inspector and two inspectors. The purpose of this section is to analyze when the framework with one inspector or that with two inspectors must be selected. For the sake of simplicity, we deal with the homogeneous inspector with regard to ability in this section, but the case of the heterogeneous inspector can be considered in a similar manner.

The problem depends on the tradeoff between the total expected inspection payment to inspectors and the social loss that occurs when an inspector overlooks the design drawing that does not meet requisite standards. Let L_S be the social loss that results from overlooking the defective design drawing. Then, let TC_1 be the total expected social cost in the framework with one inspector; it is described as

$$TC_1 = \varepsilon(1-p)L_s + g_1(v_1^*, w_1^*). \tag{22}$$

On the other hand, in the framework with two inspectors, there is no possibility that social loss occurs if only either inspector identifies the defect of the design drawing. In other words, social loss occurs only when both inspectors overlook the defects in the design drawing. Let TC_2 be the total social cost in the framework with two inspectors; it is described as

$$TC_2 = \varepsilon(1-p)^2 L_s + 2g_3(v_3^*, w_3^*, x_3^*, y_3^*). \tag{23}$$

Then, the problem with regard to whether the planner should apply the framework of one or two inspectors depends on the difference between TC_1 and TC_2.

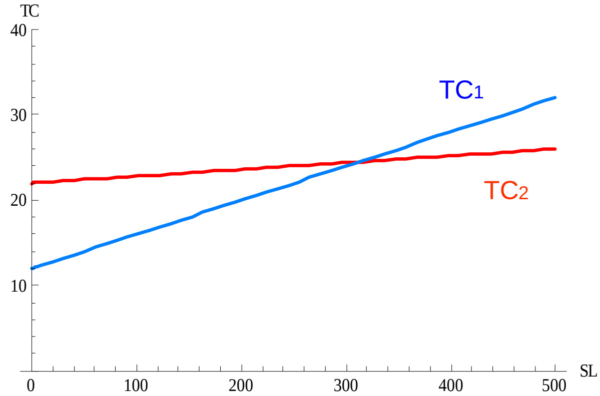

Figure 1. The effect of an increasing social loss from overlooking a defect on total social cost.

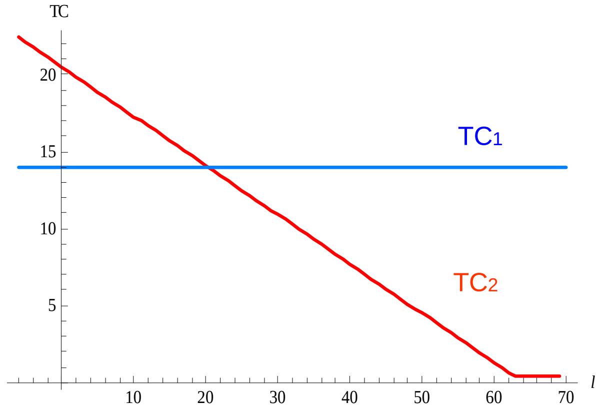

Figure 2. The effect of an increasing upper bound of penalty on total social cost.

B. Numerical Example

This section provides numerical examples for the total cost in both frameworks. In particular, we analyze the effect of the total social cost on the change in the social loss L_S, which occurs when inspectors overlooks a design drawing that does not meet requisite standards, and on the upper bound of the penalty l, which is applicable only in the framework with two inspectors.

Fig. 1 depicts the numerical example of the effect of a change in social loss L_S on TC_1 and TC_2 in the setting $\varepsilon = 0.2$, $p = 0.8$, $\psi = 6$, $\delta = 5$. In this example, the penalty mechanism in the framework of two inspectors is not applied; the cost compensation constraint for y is applied ($u(y) \ge \psi$). As shown in Fig. 1, the difference from TC_1 to TC_2 increases with the increase in the social loss L_S. This implies that if L_S is relatively large, it is more advantageous for the planner to select the framework with two inspectors.

Next, we analyze the effect of a change in the penalty l on TC_1 and TC_2. With regard to TC_2, it is easily shown that TC_2 is decreasing with l. With regard to TC_1, in the framework with one inspector, there is no possibility that the inspector who overlooked the defective design drawing assumes costly responsibility; therefore, TC_1 does not depend on l. Fig. 2 is a numerical example of

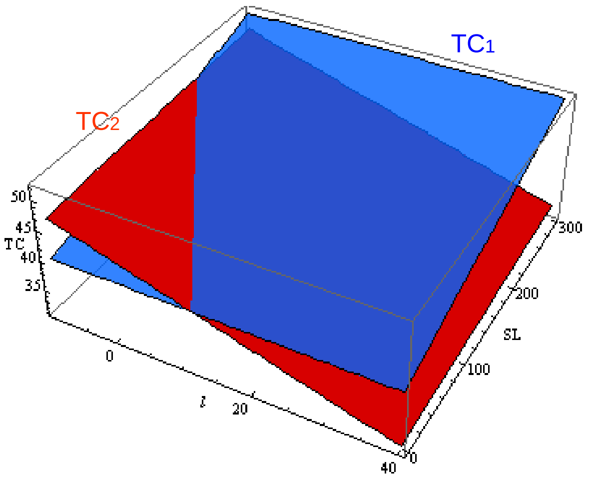

Figure 3. The effect of a change in both the social loss from overlooking a defect and the upper bound of penalty on the total social cost.

the effect of a change in the upper bound of penalty l on TC_1 and TC_2, where $\varepsilon = 0.2$, $p = 0.8$, $\psi = 6$, and $\delta = 5$. It is seen that the framework with two inspectors is more advantageous than that with one in increasing the upper bound of penalty l.

Finally, we analyze the effect in change of both the social loss L_S and l on TC_1 and TC_2. Fig. 3 presents the numerical example with parameters $\varepsilon = 0.2$, $p = 0.8$, $\psi = 20$, and $\delta = 5$. It is indicated that the planner must apply the framework with one inspector when both L_S and l are relatively small.

In addition, we provided a numerical example indicating a change in inspection cost ψ, the burden of which is borne by the inspector when exerting effort. Fig. 4 presents the numerical example where $\varepsilon = 0.2$, $p = 0.8$, $\psi = 10$, and $\delta = 5$. It is evident from the figure that the area in which the framework with one inspector should be selected is expanded. In other words, the increase in the basic cost of inspection causes the appeal of a framework with two inspectors to be lost.

VI. CONCLUSION

This paper models the decision-making of inspectors and analyzes the frameworks with one and two inspectors in order to ascertain trustworthy inspection systems. In order to ensure the motivation and ability of inspectors, which are the main components of trustworthiness, the paper analyzed a payment plan based on inspection results and indicated the appropriate combination of reward and penalty. Under the payment plans, both the moral hazard problem related to motivation and the adverse selection problem related to ability can be resolved. In addition, the paper indicated the applicability of the penalty system in the framework of two inspectors, and showed that it would be more advantageous for the planner to select the framework with two inspectors when the upper bound of penalty is relatively large. Furthermore, it is indicated that the planner should apply the framework with two inspectors in the case where the

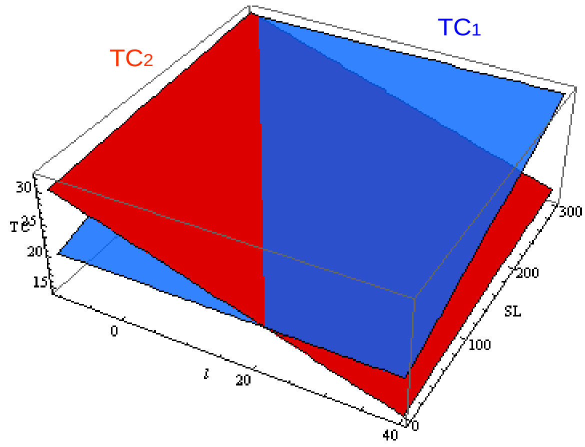

Figure 4. The effect of a change in inspection cost on the total social cost

social loss that occurs when inspectors overlook a defective design drawing is relatively large.

However, it must be noted that the implications above are the results obtained under the limited situations assumed here. First, we assumed the discrete effort level of inspectors; however, in reality, it is usual that the effort level is more likely to be continuous. In addition, it is assumed that the inspection results are of two types—whether requisite standards are met or not; however, in reality the object to be inspected may include a variety of defects. The identification of critical defects should be more highly evaluated than the identification of minor ones. In addition, our model gave the proportion of design drawings that do not meet the requisite standards externally. Our model does not include the decision-making by the agent who produces the design drawing. This extension generates other types of problems related to the interaction between agents and inspectors (e.g., coalition). The planner must be careful with regard to such a problem and consider another structure of payment plan for agents and inspectors. Lastly, our model is just a one-shot contract between the inspectors and the planner. We need to extend the model to the repeated contract model and take into consideration the demand and supply of inspection. These are topics for discussion in a future research.

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