Heliyon 9 (2023) e18579

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Government regulation strategies for inhibiting opportunistic behaviors in construction projects

Lei Cui [a], Gang Liu [b], Lanjun Luo [c,*]

[a] School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, 430074, China
[b] School of Management, Huazhong University of Science and Technology, Wuhan, 430074, China
[c] School of Management, North Sichuan Medical College, Nanchong, 637100, China

ARTICLE INFO

Keywords:
Government regulation strategy
Collusion
Moral hazard
Safety
Quality
Game theory

ABSTRACT

The construction industry has long been criticized for recurring accidents, wherein opportunistic behaviors are the primary cause of losing faith and increasing risk, infringing upon the interests of the state, society and people. While government regulation can be crucial in curbing opportunistic behaviors, the existing mixed strategy game model fails to accurately capture the strategic interactions between the government, owner, supervisor, and contractor. To bridge this gap, we propose a multi-stage dynamic game model with asymmetric information in the context of a typical construction project, wherein two urgent opportunistic behaviors may arise: moral hazard and covert collusion. According to project characteristics, the regulatory issues are further classified as hidden information for general projects and hidden effort for dominant projects. On this basis, the government's optimal regulation strategies are derived, i.e., the optimal fines for poor quality and the optimal fine coefficient for quality effort reduction. Subsequently, several significant managerial implications are presented to summarize and analyze impacts of government regulation on construction projects. The findings show that government regulation can achieve systemic optimality but may hurt the owner's interests in some cases. This could potentially hinder the healthy development of the construction industry as the owner may forgo purchasing the construction project. Furthermore, general projects are more vulnerable to opportunistic behaviors as opposed to dominant projects. The developed model and derived regulatory strategy can assist the government in more effectively governing and controlling opportunistic behaviors. This research also contributes several valuable managerial insights into the domain of government regulation on construction projects.

1. Introduction

The construction field has been considered as the most active sector in employing people, generating revenue, and increasing the Gross Domestic Product (GDP) of any country [1]. According to the US Bureau of Economic Analysis, the GDP from construction is estimated to be around 690.7 billion dollars in 2021. Unfortunately, the construction industry is long criticized for recurring accidents [2]. Particularly, the incidents caused by poor quality can result in underperformance of construction projects, such as safety incidents and benefit shortfalls [3,4]. It will not only seriously infringe upon the interests of the state, society, and the people but also cause huge

* Corresponding author.
E-mail address: lanjun@nsmc.edu.cn (L. Luo).

https://doi.org/10.1016/j.heliyon.2023.e18579
Received 23 November 2022; Received in revised form 12 July 2023; Accepted 20 July 2023
Available online 27 July 2023
2405-8440/© 2023 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

losses to people's lives and property [5]. These accidents may be caused by individual behaviors that directly contribute to accidents [6] or organizational factors that influence individual behavior [7,8]. Generally, the majority of issues stem from human factors, wherein professional ethics play a pivotal role in mitigating quality problems and preventing inconvenience to all parties [9].

A construction project is realized through the collaboration of a multitude of stakeholders, including the owner, contractors, construction supervisor, and other relevant parties. However, they have their own self-interests, which are frequently divergent and competing in nature [9]. Especially, the owner typically can't control all the agents' activities and an information imbalance in favor of agents occurs. The agents can use this situation opportunistically [10]. Consequently, the absence of professional ethics may result in opportunistic behaviors, which are the primary cause of losing faith and increasing risk in the construction market [11]. In construction projects, there are two urgent opportunistic behaviors. For one thing, the contractor may engage in moral hazard behaviors to save construction costs, such as using inferior materials or reducing design standards [12]. For another, for fear of rework or penalty, the contractor may collude with the supervisor to conceal the evidence of poor quality. The collusive pact is one of the primary corruptive practices in construction projects [13]. To inhibit these opportunistic behaviors, government regulation should intervene and play an essential role in the construction market [14,15]. Xia et al. [16] also argued that workplace accidents and injuries could be highly reduced through improvements in legal frameworks, such as rules and enforcement. Nevertheless, over and under regulation co-exist in the construction industry [15]. Therefore, how to determine the optimal government regulation strategy is a fundamental challenge for project success and public interests.

Game theory provides effective tools for analyzing situations wherein the players make interdependent decisions. This theory has been applied to a wide variety of situations in which the choices of players interact to affect the outcome, such as construction management [17], coal mining safety inspection [18], and speed enforcement [19]. The existing framework formulates the government regulation problem as a standard mixed strategy game model, wherein the regulated objects decide whether to act opportunistically while the government simultaneously determines whether to regulate. Nevertheless, the current game model fails to accurately capture the strategic interactions between the multiple stakeholders, which is a standard multi-stage dynamic game process. Especially, there exists severe information asymmetry in construction projects. For instance, the contractor generally possesses more quality information than the owner. Additionally, the existing framework typically treats collusive conduct as detectable. In fact, corruption is virtually covert in the informal underground arena [20] and proving illegal transactions is a pervasive challenge [21].

Based on the above analysis, this paper develops a multi-stage dynamic game model with asymmetric information for construction projects. In the proposed model, the low-quality project will occur accidents with some probability, which can generate some social welfare losses, such as personnel casualties. On the premise of preventing opportunistic behaviors, the government aims to maximize the interests of the entire system which comprises the owner, supervisor, contractor, and government. By contrast, the other players pursue the maximum of their self-interests. According to project characteristics, construction projects are divided into general projects and dominant projects. For dominant projects, the supervisor can observe the contractor's effort perfectly. Instead, for general projects, the supervisor only spot-checks the construction projects for reasons of costs or personnel. The government conducts spot checks on both kinds of construction projects. In moral hazard scenarios where the contractor may reduce private quality efforts to save construction costs, the government determines optimal fines (coefficient) for the contractor for general (dominant) projects. Furthermore, to manage the secret collusion between the supervisor and the contractor, the government determines optimal fines (coefficient) for the supervisor and the contractor for general (dominant) projects, respectively.

The main contributions of this study are summarized as follows. First, this research investigates the optimal government regulation strategy that inhibits opportunistic behaviors in construction projects. The proposed practical regulation strategy can help the government in managing and controlling opportunistic behaviors. Second, compared with the present regulation framework, a multi-stage dynamic game model with asymmetric information is developed to characterize the multiplayer strategic interaction. Particularly, the symbiotic relationship between quality and safety is adopted in the constructed model. The developed framework is more suitable for the construction project context. Finally, several novel managerial implications are proposed to reveal the effects of government regulation on construction projects with opportunistic behaviors. Those implications can play significant roles for the government regulator in better coping with quality and safety challenges caused by opportunistic behaviors in construction projects.

The structure of this paper is as follows. Section 2 reviews the related literature. The research model is presented in Section 3. In Section 4, optimal government regulation strategies in different settings are derived. Section 5 provides some notable managerial implications. Some discussions are made in Section 6. Finally, Section 7 concludes this paper.

2. Literature review

This research is connected to literature concerning government regulation. Government regulation can use the coercive power of the state to alter a firm's pricing, entry, production, investment, and product choice decisions. The current regulation literature about construction projects includes the role of regulation [22,23], corruption [3], implementation level [24], regulation strategy [25], etc. The existing literature about regulation strategy adopts game theory as the analytical tool. To improve the efficiency of quality supervision and reduce moral hazard, Yang et al. [26] established a system dynamics evolution game model among the inspection unit, contractor, and supervising unit. To prevent collusion between the supervisor and the contractor, Yu et al. [25] proposed a dynamic analysis model of the evolutionary game in collusion control based on the system dynamics model. However, this line of research has several limitations that need to be noted. First, the strategic interactions between the supervisees are ignored. Specifically, the supervisor can play a positive role in controlling the contractor's moral hazard but may collude with the contractor. In addition, there is no strategic response from the owner. In practice, the owner provides the commission contracts in which the payments and obligations are specified. Government regulation strategy should build on these commission contracts. Otherwise, over and under regulation problems will be present. Second, the current studies view the strategic interaction between participants as simultaneous. In fact, the government moves firstly to determine regulation strategies, such as penalty regulations, etc. After that, the other participants in turn react strategically. Third, the existing literature fails to characterize the symbiotic relationship between quality and safety. Quality defects can lead to safety incidents, which can result in massive social welfare loss. For one thing, defects or failures can jeopardize the safety of public life and property. For another, safety and quality performance share a symbiotic relationship [27], and a significant correlation exists between recordable injury rate and rework and the number of defects [28]. Naturally, when an action on a non-conforming product to ensure it conforms to specified requirements is undertaken, the potential for a safety event to occur significantly increases [27]. Finally, this framework assumes collusion behaviors can be detected by outsiders. In practice, corruption is virtually covert in the informal underground arena [20], and proving the transactions is a pervasive challenge [21]. To solve these challenges, this study develops a multi-stage dynamic game model with asymmetric information to characterize the strategic actions between the players. Since the multiplayer game contains multiple rounds of strategic interactions, backward induction is applied to ensure the subgame perfection.

The second related stream is related to literature about incentive mechanisms for moral hazards. This stream of literature can be divided into cost incentives [29–32], duration incentives [26,33], quality incentives [34,35], and safety incentives [36]. In the line of quality incentive research, Jaraiedi et al. [37] examined the use of incentive/disincentive (I/D) contracts in many states and the experience of several contractors and developed a general set of guidelines for the use of I/D provisions in highway construction or refurbishing contracts. Meng and Gallagher [38] empirically investigated the impact of incentive mechanisms on project performance in the United Kingdom. To improve the performance of government procurement of public services, Zhang and Xu [39] designed quality incentive contract models under the condition of dual asymmetric information. Gao et al. [40] developed quality incentive contracts considering asymmetric product manufacturability information. In summary, the existing research is built on the standard principal-agent structure, wherein the government typically serves as the principal rather than the regulator. Particularly, this work investigates the effects of covert supervisor-contractor collusion on government regulation.

This article also builds on the growing economic literature on collusion. The pioneering work of Tirole [41] proposed the principle of collusion prevention that the principal can prevent collusion by a collusion-*proof* grand contract. Strausz [42] studied a principal-agent relationship in which either the principal or a supervisor can monitor the agent's hidden action using identical monitoring technologies. Faure-Grimaud et al. [43] put forward the equivalence principle that the non-centralized mechanism can replace the optimal centralized mechanism. Vafaï [44] investigated how the possibility of collusion between members of an organization affects the choice of organization design. Khalil et al. [45] analyzed the distinction between bribery and extortion, both in their impact on incentives for agents to obey rules and for corrupt parties to engage in illegal transactions. Ortner and Chassang [46] modeled the investigation of criminal activity as a principal-agent-monitor problem in which the agent can corrupt the monitor and side-contract to destroy evidence. In all, the existing works consider a tripartite principal-supervisor-agent structure wherein the principal manages the supervisor-agent collusion. By constrast, this paper constructed a quadruple structure wherein the government rather than the principal is responsible for regulating collusive behaviors. The results show that government regulation can effectively prevent opportunistic behaviors but may undermine the principal's interests.

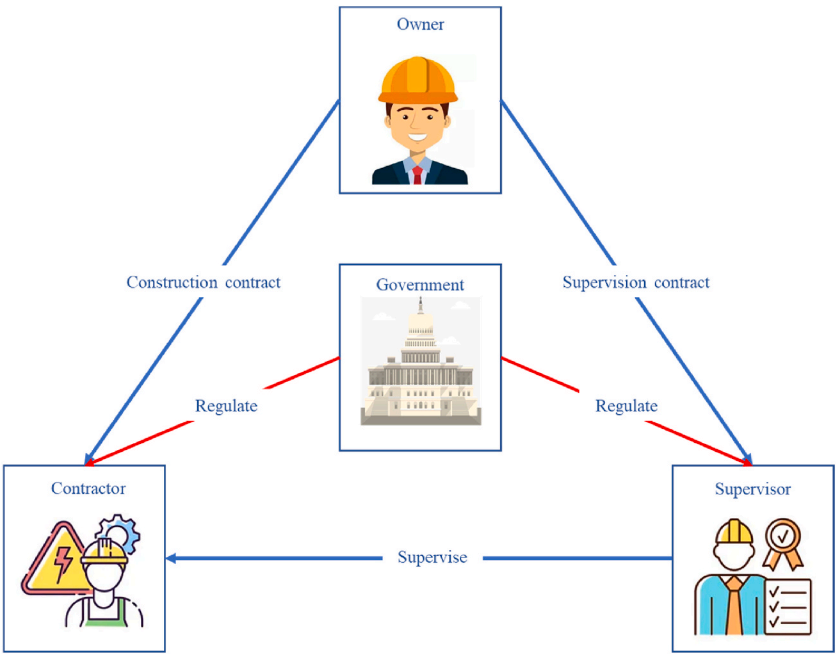


Fig. 1. Relationships between the players.

In summary, this study significantly differs from previous research in several critical aspects. Firstly, a novel multi-stage dynamic game model with asymmetric information is developed to characterize the strategic interactions between multiple players in a construction context. Secondly, the government's role as a regulator rather than as a principal is investigated. The government aims to maximize the system's expected payoffs instead of its own interests. Finally, we analyze impacts of government intervention on construction projects that encounter opportunistic behaviors.

3. Model development

We consider a typical construction project context that comprises four players: an owner, a supervisor, a contractor, and the government [47]. The owner, as the development organization or the developer, is the buyer of the construction project products, while the contractor is the seller. The supervisor, including the supervision unit and advisory body, is employed by the owner to conduct supervision and management or advisory services. The government is responsible for regulating and managing the participants' opportunistic behaviors during construction. All players are risk-neutral, and their reserved payoffs are normalized to zero. For the sake of simplicity, their relationships are illustrated in Fig. 1.

Project quality is divided into two levels $q \in \{q_h, q_l\}$ [48]. For the project owner, the project with $q = q_h$ is referred to as high quality and generates the profit Q_h, while the project with $q = q_l$ is referred to as low quality and generates a profit Q_l. Q_h is high enough that the owner always prefers to receive a high-quality project, thus the gap $\Delta = Q_h - Q_l > 0$. When the project quality is low, i.e., $q = q_l$, safety accidents may occur with probability $\eta \in (0, 1)$, which generate some social welfare losses L for the government, such as building collapses causing casualties [17].

The project quality depends on the contractor's private effort e and events that are outside of the contractor's influence [49]. After the contractor exerts quality efforts e, nature determines project quality q, where $\Pr\{q = q_h|e\} = e$ [48]. To reflect the effect of diminishing marginal utility in the construction process, the impact of the effort on cost is assumed to be quadratic [39,49,50]. Formally, the cost function is $C(e) = ce^2$, wherein the constant c denotes the cost coefficient. The owner provides a construction contract that specifies the contract price t and penalty terms β for low quality [51]. The penalty terms β should be no more than a threshold of Ω, i.e., $\beta \leq \Omega$. The threshold of Ω reflects the practice that the contractor is protected by limited liability, such as quality bonds [35].

The construction projects are divided into two categories. One is the dominant project that plays a decisive role in safety, health, environmental protection, and public interest. The other is the general projects that refer to the projects out of the dominant projects. For dominant projects, the supervisor should supervise the entire construction process on-site, so the contractor's effort e is observable to the supervisor. For the general project, the supervisor only spot-checks the construction project due to the lack of time or persons, etc. The probability is denoted by p, which is common knowledge because the supervision schedule is typically determined before the start of construction. The owner provides the construction supervisor with a fixed-price supervision contract that specifies the supervision fees S [52].

The government spot-checks construction projects with the probability ξ. According to *Wuhan City Urban and Rural Construction Administrative Punishment Discretionary Benchmarks*, the government imposes fines of $f(e_0 - e)$ on the contractor once $e \leq e_0$, wherein f denotes the fine coefficient and e_0 is standard effort, like technical standards or construction solutions. The government determines the fines of φ on the contractor once $q = q_l$. For fear of covert collusion, the government imposes fines of $f_c(e_0 - e)$, $f_s(e_0 - e)$ when $e \leq e_0$ and φ_s, φ_s when $q = q_l$ on the contractor and the supervisor, respectively. For convenience, Table 1 summarizes these parameters.

Table 1
Notations of parameters.

Parameters	Description
q	Actual quality
q_l	Low quality
q_h	High quality
L	Social welfare losses
η	Probability of occurring accidents
e	Contractor's private effort
e_0	Standard effort
p	Probability of detecting low quality
c	Cost coefficient
Q_h	Profits of high quality
Q_l	Profits of low quality
Δ	Profit gap
ξ	Spot check probability
f	Fine coefficient for the contractor
φ	Fines to the contractor for moral hazard
t	Contract price
β	Penalty to the contractor
f_s	Fine coefficient to the supervisor
f_c	Fine coefficient to the contractor
Ω	The contractor's limited liability
S	Supervision fees

4. Analysis

This section first investigates the contractor's moral hazard and then explores the supervisor-contractor collusion for different projects. The optimal government regulation strategies will be derived based on the developed dynamic game-theoretic model, and several propositions will be presented to characterize the nature of the equilibrium outcomes.

4.1. Moral hazards

The owner (principal) can't control all the contractor's activities, and an information imbalance in favor of the contractor (agent) can occur. Moral hazards mean the agent can use this situation opportunistically [10]. Specifically, the contractor may reduce a private quality effort in dominant projects or conceal quality information in general projects.

4.1.1. Dominant projects

Before deriving the optimal regulation strategies of the government, the game sequence between the players is shown as follows. First, the government decides on the fines of $f(e_0 - e)$ and the standard effort e_0. Second, the owner provides the construction contract that specifies the contract price t and the penalty terms $\beta(e_0 - e)$ for the contractor failing to meet the standard effort e_0. Third, the contractor determines private efforts e. Fourth, the supervisor learns the effort e and reports to the owner. Finally, project quality is realized, and low-quality projects will occur some safety accidents with probability η. This game process between the players is summarized in Fig. 2.

Since the game contains multiple rounds of strategic interactions, backward induction is applied to ensure subgame perfection. In the fourth stage, for the supervisor always reports truthfully, the owner pays fixed fees $S = 0$. In the third stage, the contractor's payoffs consist of the contract price t, the effort costs ce^2, and the fines $(e_0 - e)(f + \beta)$, which are $\Pi_{CE} = t - ce^2 - (e_0 - e)(f + \beta)$. The contractor determines the private quality effort e to maximize its expected payoffs Π_{CE}. Therefore, the contractor's incentive compatibility constraint is given as follows

$$e = \underset{e}{\text{argmax}} \Pi_{CE} \tag{1}$$

in the second stage, the owner's expected payoffs are the expected project profits $Q_h + (1 - e)Q_l$ minus the contract price t and plus the fines of $(e_0 - e)\beta$ imposed on the contractor, which are formally given by $\Pi_{OE} = eQ_h + (1 - e)Q_l - t + (e_0 - e)\beta$. Given equation (1), the owner determines contract price t and penalty terms β to maximize its expected payoffs Π_{OE}. Accordingly, the owner's optimization programming can be characterized by

$$\begin{aligned} & \max_{e\in[0,1],t\geq 0,\beta\in[0,\Omega]} \Pi_{OE}, \\ \text{Subject to} \quad & \Pi_{CE} \geq 0, \\ & e = argmax_e \Pi_{CE} \end{aligned} \tag{2}$$

Solving this constraint optimization problem (2) yields the equilibrium outcomes that are summarized in Lemma 1.

Lemma 1. *The optimal construction contracts provided by the owner are given by:*

	Owner	***Contractor***
When $\Omega \leq \Delta$,	$\beta = \Omega,\ t = \frac{(\Delta + f)(4ce_0 - \Delta - \Omega)}{4c}.$	$e = \frac{\Omega + f}{2c}.$
When $\Omega > \Delta$,	$\beta = \Delta,\ t = \frac{(\Delta + f)(4ce_0 - \Delta - f)}{4c}.$	$e = \frac{\Delta + f}{2c}.$

In the first stage, the government's expected payoffs Π_{GE} are the fines $f(e_0 - e)$ minus the possible social welfare loss $(1 - e)\eta L$, which are $\Pi_{GE} = f(e_0 - e) - (1 - e)\eta L$. However, the government aims to determine (e_0, f) to maximize the construction system's expected payoffs Π_{SE}, which are composed of all participants' expected payoffs, i.e., $\Pi_{SE} = eQ_h + (1 - e)Q_l - ce^2 - (1 - e)\eta L$. Therefore, the optimization program for the government is given by

$$\max_{e\geq e_0,f\geq 0} \Pi_{SE} = eQ_h + (1 - e)Q_l - ce^2 - (1 - e)\eta L \tag{3}$$

By solving the optimization problem (3), we derive final equilibrium outcomes as summarized by Corollary 1.

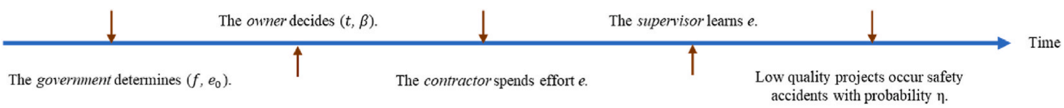


Fig. 2. The sequence of events for dominant projects with moral hazards.

Corollary 1. When dominant projects face contractor's moral hazards, in equilibrium:

Players	Decision variables
Government	$f = \begin{cases} \Delta + \eta L - \Omega, & \Omega \le \Delta \\ \eta L, & otherwise \end{cases}$, $e_0 = \begin{cases} \dfrac{\Delta + \eta L}{2c}, & \eta L \le 2c - \Delta \\ 1, & otherwise \end{cases}$.
Owner	$\beta = \begin{cases} \Omega, & \Omega \le \Delta \\ \Delta, & otherwise \end{cases}$, $t = \begin{cases} \dfrac{(\Delta + \eta L)(4c - \Delta - \eta L)}{4c}, & \eta L \le 2c - \Delta \\ \Delta + \eta L - c, & otherwise \end{cases}$.
Contractor	$e = \begin{cases} \dfrac{\Delta + \eta L}{2c}, & \eta L \le 2c - \Delta \\ 1, & otherwise \end{cases}$.

When the contractor has a relatively low liability ($\Omega \le \Delta$), the fine coefficient $f = \Delta + \eta L - \Omega > \eta L$. In other words, the government should set a higher fine coefficient for the contractor with lower liabilities. Meanwhile, when social welfare losses are relatively low ($\eta L \le 2c - \Delta$), the standard effort $e_0 = \frac{\Delta + \eta L}{2c} < 1$. Therefore, the possibility of occurring a safety accident is $\left(1 - \frac{\Delta + \eta L}{2c}\right)\eta > 0$. Furthermore, the optimal quality effort exerted by the contractor is equal to the standard quality effort e_0, i.e., government regulation can effectively prevent contractor's moral hazards.

Proposition 1. For dominant projects, the impacts of social welfare losses L are summarized as follows:

(i) $\frac{\partial e_0}{\partial L} \ge 0$ holds, i.e., the standard effort e_0 is increasing in social welfare losses L.
(ii) $\frac{\partial \Pi_{OE}}{\partial L} \le 0$ holds, i.e., the owner's expected payoffs Π_{OE} are decreasing in social welfare losses L.

As the social welfare losses L increase, the government improves the standard effort e_0 to reduce the possible social welfare losses and sets a higher fine coefficient to force the selfish contractor to achieve the standard effort. However, the standard effort exceeds the effort that the owner intends to induce, i.e., $e_0 = \frac{\Delta + \eta L}{2c} > \frac{\Delta}{2c}$. To induce the contractor to produce the construction project, the owner needs to provide the contractor with a higher contract price. Therefore, the owner's expected payoffs decrease in social welfare losses L accordingly. Especially, in the case of $\eta L > 2c - \Delta$, the social welfare losses are too severe that the government always would like to induce the profit-maximizing contractor to exert a quality effort equal to 1. The graphical illustration of Proposition 1 is shown in Fig. 3.

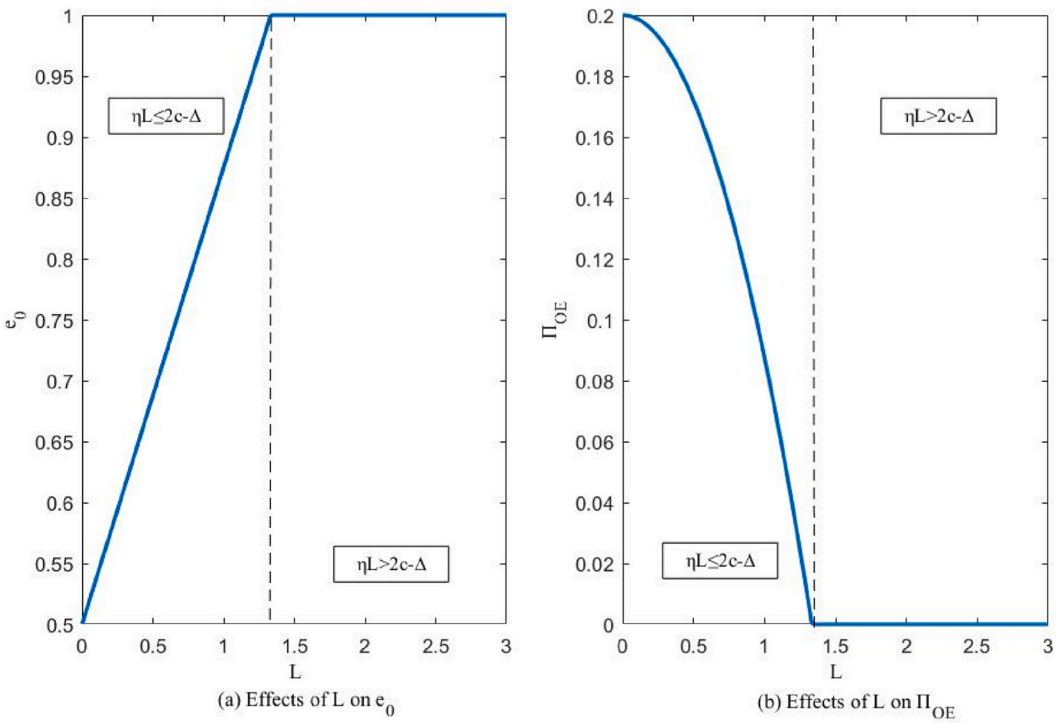


Fig. 3. Effects of L on e_0 and Π_{OE} respectively when $Q_h = 0.8, Q_l = 0, \eta = 0.1, c = 0.6, p = 0.6$.

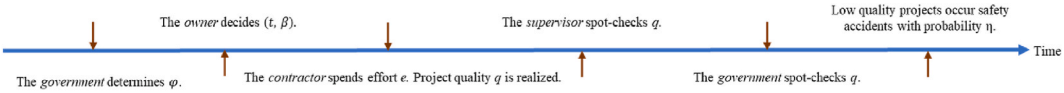


Fig. 4. The sequence of events for general projects with moral hazards.

4.1.2. General projects

For general projects, the sequence of the game is as follows. First, the government determines the fines of φ for the contractor. Second, the owner provides the construction contract that specifies the contract price t and the penalty term β for low quality. If the contractor rejects, the game ends. Third, the contractor exerts a quality effort e, and then nature determines project quality q. Fourth, the supervisor spot-checks the project quality with probability p and submits quality reports to the owner. Fifth, the government spot-checks project quality with probability ξ. Sixth, low-quality projects will occur safety accidents with probability η. The game process is summarized in Fig. 4.

Since the game contains multiple rounds of strategic interactions, backward induction is applied to ensure subgame perfection. In the fourth stage, the benevolent supervisor will always report truthfully. Thus, the owner pays the fixed supervision fees equal to zero. In the third stage, the contractor's expected payoffs include the contract price t, the construction costs ce^2, the expected penalties of $(1-e)[p+(1-p)\xi]\beta$ imposed by the owner, and the expected fines of $(1-e)(1-p)\xi\varphi$ imposed by the government, which are given by $\Pi_{CG} = t - ce^2 - (1-e)[p+(1-p)\xi]\beta - (1-e)(1-p)\xi\varphi$. The contractor determines the private quality effort e to maximize its expected payoffs Π_{CG}. Therefore, the contractor's incentive compatibility constraint is given by

$$e = \underset{e}{\text{argmax}} \Pi_{CG} \tag{4}$$

in the second stage, given equation (4), the owner determines the contract price t and the penalty term β to maximize the owner's expected payoffs Π_{OG}, which are $\Pi_{OG} = eQ_h + (1-e)Q_l - t + (1-e)[p+(1-p)\xi]\beta$. The contractor's individual rationality constraint should be satisfied, which is formally given by $\Pi_{CG} \geq 0$. Otherwise, the contractor will not join in the production of the project. Now, the owner's optimization program can be summarized as

$$\begin{aligned} & max_{e\in[0,1],t\geq 0,\beta\in[0,\Omega]} \Pi_{OG} \\ \text{Subject to} \quad & \Pi_{CG} \geq 0, \\ & e = \arg\max_e \Pi_{CG}, \end{aligned} \tag{5}$$

Solving the above mathematical programming (5) derives the equilibrium outcomes, as summarized in Lemma 2.

Lemma 2. The optimal construction contracts provided by the owner are given by:

	Owner	Contractor
When $\boldsymbol{\Omega} \geq \dfrac{\Delta}{\boldsymbol{p}+(\mathbf{1}-\boldsymbol{p})\boldsymbol{\xi}}$	$\beta = \dfrac{\Delta}{p+(1-p)\xi}$ $t = \dfrac{\Delta+(1-p)\xi\varphi}{4c}[4c - \Delta - (1-p)\xi\varphi]$	$e = \dfrac{\Delta+(1-p)\xi\varphi}{2c}$
When $\boldsymbol{\Omega} < \dfrac{\Delta}{\boldsymbol{p}+(\mathbf{1}-\boldsymbol{p})\boldsymbol{\xi}}$	$\beta = \Omega$, $t = \dfrac{\Psi(4c-\Psi)}{4c}$, *where* $\Psi = [p+(1-p)\xi]\Omega + (1-p)\xi\varphi$	$e = \dfrac{\Psi}{2c}$

In the first stage, the government's expected payoffs are $\Pi_{GG} = (1-e)(1-p)\xi\varphi - (1-e)\eta L$. The goal of the government is to determine the fines φ to maximize the expected payoffs of the construction system Π_{SG}, which is the sum of the owner's expected payoffs Π_{OG}, the contractor's expected payoffs Π_{CG}, and the government's expected payoffs Π_{GG}. Namely, $\Pi_{SG} = eQ_h + (1-e)Q_l - ce^2 - (1-e)\eta L$. Thus, the government's optimization problem is

$$\max_{\varphi} \Pi_{SG} = eQ_h + (1-e)Q_l - ce^2 - (1-e)\eta L \tag{6}$$

By solving the government's optimization problem (6), we derive the following equilibrium.

Corollary 2. *When general projects face contractor's moral hazards, in equilibrium:*

Players	Decision variables
Government	$\varphi = \begin{cases} \dfrac{\Delta+\eta L-[p+(1-p)\xi]\Omega}{(1-p)\xi}, & \text{for } \Omega \leq \dfrac{\Delta}{p+(1-p)\xi}. \\ \dfrac{\eta L}{(1-p)\xi}, & \text{otherwise} \end{cases}$

(*continued on next page*)

(*continued*)

Players	Decision variables
Owner	$\beta = \begin{cases} \Omega, & \Omega \le \dfrac{\Delta}{p+(1-p)\xi} \\ \dfrac{\Delta}{p+(1-p)\xi}, & otherwise \end{cases}, t = \dfrac{(\Delta+\eta L)(4c-\Delta-\eta L)}{4c}.$
Contractor	$e = \begin{cases} \dfrac{\Delta+\eta L}{2c}, & \eta L \le 2c-\Delta \\ 1, & otherwise \end{cases}.$

For general projects, $\partial e/\partial L \ge 0$, which means the contractor will exert more effort as social welfare losses L increase. The reason is that to reduce the possible social welfare losses, the government sets high fines on the contractor, i.e., $\partial \varphi/\partial L \ge 0$. As for the owner, when $\eta L \le 2c - \Delta$, $\partial t/\partial L \ge 0$, i.e., the owner should increase the contract price t as the social welfare losses L increase. Otherwise, $\partial t/\partial L < 0$, thus the owner should decrease the contract price.

Proposition 2. *For general projects, when $\Delta > [p+(1-p)\xi]\Omega$ and $\eta L > 2c + [p+(1-p)\xi]\Omega - 2\Delta$, the owner's expected payoffs Π_{OG} increase in social welfare losses L. Otherwise, the owner's expected payoffs decrease in L.*

When $\Delta > [p+(1-p)\xi]\Omega$ and $\eta L \le 2c + [p+(1-p)\xi]\Omega - 2\Delta$, the marginal benefits Δ are less than the marginal costs $g(L) = 2c + [p+(1-p)\xi]\Omega - \Delta - \eta L$. Therefore, the owner suffers losses from government regulation. However, $\partial g(L)/\partial L = -\eta \le 0$. As the welfare losses increase, the marginal benefit exceeds the marginal costs, and the owner can benefit from the government regulation thereby. Instead, when $\Delta \le [p+(1-p)\xi]\Omega$, the government induces the contractor to exert an effort that is more than the optimal quality effort the owner prefers. Therefore, the owner's expected payoffs are decreasing in social welfare losses L. Furthermore, when $\eta L > 2c - \Delta$ the social welfare losses are so expensive that the government always induces the contractor to spend a quality effort that is equal to one. Hence, the owner's expected payoffs Π_{OG} do not change with social welfare losses L. The graphical illustration of the effects of social welfare losses L on the owner's expected payoffs Π_{OG} is given in Fig. 5.

4.2. Covert collusion

This section examines the collusive scenario in which a self-serving supervisor may manipulate the supervision report in exchange for bribes from the contractor. Unethical collusive behaviors are common phenomena, and the collusive pact between the supervisor and contractor is one of the primary collusive practices in construction projects [12,13]. A typical example is a major accident in the

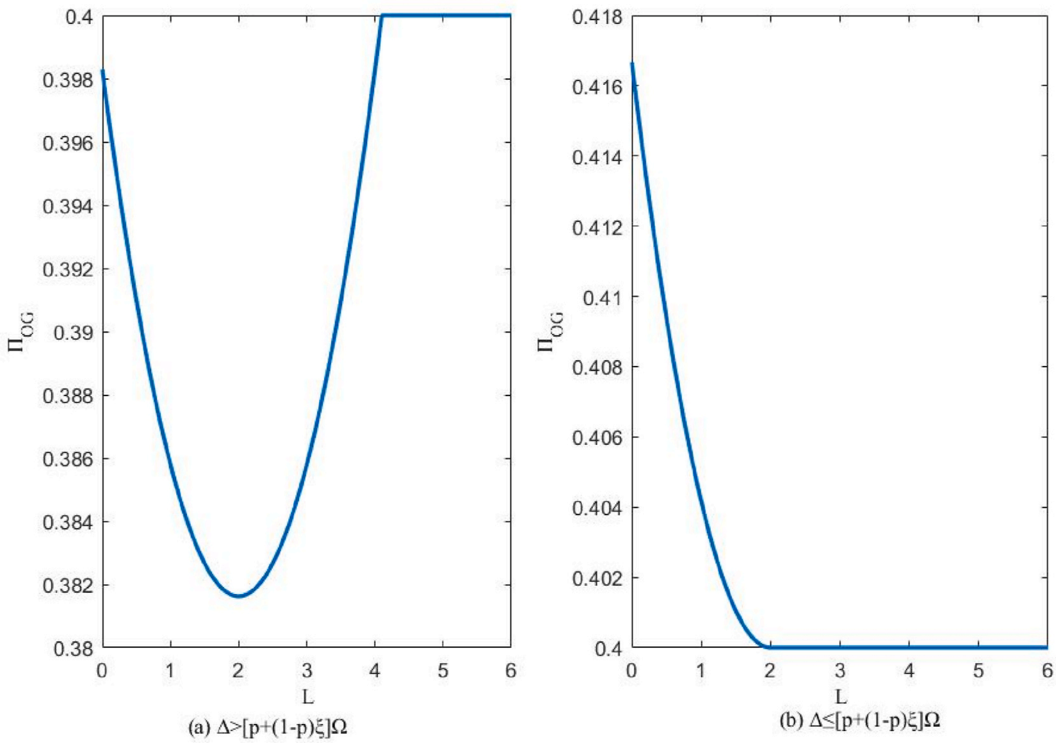


Fig. 5. *Effects of L on Π_{OG} when $Q_h = 1, Q_l = 0, \eta = 0.1, c = 0.6, p = 0.7, \xi = 0.3$.*

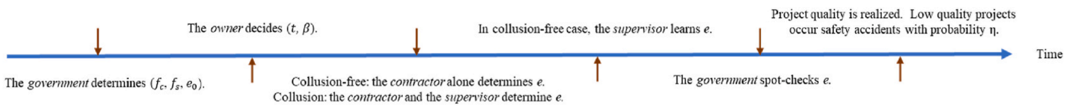


Fig. 6. The sequence of events for dominant projects with collusion.

Guizhou section of the Shanghai-Kunming high-speed railway in 2017. Gansu Tieke Supervision Company was negligent in on-site monitoring and signed off the internal data arbitrarily, which finally led to the collapse of the diversion cave of the Baiyan Foot Tunnel, causing some serious economic losses.

Unofficial activities generally involve unofficial commitments, such as threats and promises, because the conspirators should be able to credibly abide by their promises when reaching an agreement. Since unofficial commitments cannot be enforced by a third party, e.g., the court, there need some strategies that can ensure compliance with unofficial commitments, such as reputation and reciprocity [45, 53]. Following this literature, we assume the unofficial commitments are self-enforceable. Furthermore, proving collusion in public procurement is a pervasive challenge, especially in court for public prosecutors; despite plea agreements, proof of the crimes is still lacking in many cases [21]. Therefore, the side transactions among colluders are well hidden and can't be directly forbidden [54].

4.2.1. Dominant projects

Before deriving the optimal regulation strategies of the government, the sequence of the game is given as follows. First, the government determines the fines of $f_c(e_0 - e), f_s(e_0 - e)$ to the contractor and the supervisor, respectively and standard quality effort e_0. Second, the owner specifies the contract price t and the penalty term $\beta(e_0 - e)$ for the contractor. Third, the supervisor and the contractor decide whether to collude. In a collusion-free case, the contractor alone determines the private effort e; otherwise, they jointly determine the effort e. Finally, project quality is realized, and low-quality projects will occur safety accidents with probability η. This game sequence is summarized in Fig. 6.

Since the game contains multiple rounds of strategic interactions, backward induction is applied to ensure subgame perfection. In the third stage, when collusion does not occur, i.e., the contractor spends the standard quality effort e_0, the collectively expected payoffs of the contractor and the supervisor are $\Pi_{CF} = t - ce_0^2$. Instead, in the collusive context, they jointly determine a quality effort that $e \le e_0$. The contractor can save costs, but they face the possibility of fines for this. Therefore, their collective expected payoffs are $\Pi_E^c = t - ce^2 - \xi(e_0 - e)(f_c + f_s + \beta)$.

From the perspective of the supervisor and the contractor, their goal is to jointly determine e to maximize the expected payoffs Π_{CC}. By applying first-order conditions, the contractor spends an effort e_c as shown in equation (7).

$$2ce_c - \xi(f_c + f_s + \beta) = 0 \tag{7}$$

To prevent supervisor-contractor collusion, their expected payoffs in the case of collusion should be less than that in the case without collusion, i.e., $\Pi_{CF} \ge \Pi_E^c$. Therefore, the following collusion-proof onstraint should be satisfied

$$2ce_0 - \xi(\beta_c + \beta_s + \beta) \le 0 \tag{8}$$

In the second stage, when the collusion-proof constraint (8) is satisfied, the owner achieves a same equilibrium as that in.Lemma 1 Here it will not be reported again. Therefore, the government's constraint optimization problem is.

$$\begin{array}{ll} & \max_{f_c, f_s \ge 0, e_0 \in [0,1]} \Pi_{SE}^c = eQ_h + (1-e)Q_l - ce^2 - (1-e)\eta L. \\ \text{Subject to} & 2ce_0 - \xi(\beta_c + \beta_s + \beta) \le 0. \end{array} \tag{9}$$

By solving the above optimization problem (9), we can derive the following equilibrium.

Corollary 3. *When dominant projects face the threat of collusion, in equilibrium:*

Players	Decision variable
Government	$f_c = \begin{cases} \Delta + \eta L - \Omega, & \text{for } \Omega \le \Delta \\ \eta L, & \text{otherwise} \end{cases}, f_s \ge (\Delta + \eta L)\left(\frac{1}{\xi} - 1\right), e_0 = \begin{cases} \frac{\Delta + \eta L}{2c}, & \eta L \le 2c - \Delta \\ 1, & \text{otherwise} \end{cases}.$
Owner	$\beta = \begin{cases} \Omega, & \Omega \le \Delta \\ \Delta, & \text{otherwise} \end{cases}, t = \begin{cases} \frac{(\Delta + \eta L)(4c - \Delta - \eta L)}{4c}, & \eta L \le 2c - \Delta \\ \Delta + \eta L - c, & \text{otherwise} \end{cases}.$
Contractor	$e = \begin{cases} \frac{\Delta + \eta L}{2c}, & \eta L \le 2c - \Delta \\ 1, & \text{otherwise} \end{cases}.$

Compared with the moral hazard problem, the presence of collusion forces the government to provide incentives to the supervisor. For dominant projects, since the supervisor can observe the contractor's effort directly when the government learns that $e < e_0$, the government can impose a high enough fine to let the supervisor give up collusion. Moreover, for fear of abusing authority, this coefficient should be set to a minimum value of $f_s = (\Delta + \eta L)(1/\xi - 1)$.

Proposition 3. Under the threat of collusion, the fine coefficient f_s has following characteristics:

(i) $\frac{\partial f_s}{\partial L} \geq 0$ holds, i.e., the fine coefficient f_s increases with social welfare losses L.
(ii) $\frac{\partial f_s}{\partial \xi} \leq 0$ holds, i.e., the fine coefficient f_s decreases with probability ξ.

As social welfare losses L increase, the government needs to raise the standard effort e_0, which in turn improves collusion surplus for the colluders. Therefore, the government determines a higher fine coefficient to prevent collusion. Moreover, as the probability ξ of government's spot checks increases, it is more likely to discover the fact that the contractor exerts a substandard effort, resulting in less collusion surplus. Hence, the government can set a smaller fine coefficient for the supervisor. The graphical illustration of the fine coefficient f_s for the supervisor is shown in Fig. 7.

4.2.2. General projects

For general projects, the game process under threat of collusion is given as follows. First, the government decides on the fines φ_s, φ_c on the supervisor and the contractor, respectively. Second, the owner provides the construction contract specifying the contract price t and penalty terms β, and the supervision contract specifying the supervision fees S. If anyone rejects, the game ends. Third, the contractor determines the effort e, and then nature determines quality q. Fourth, the supervisor spot-checks project quality and decides whether to collude. Fifth, if the supervisor reports low quality, the owner imposes a penalty β; otherwise, the government spot-checks the project with probability ξ. Finally, low-quality projects occur safety accidents with probability η. The game process is summarized in Fig. 8.

Since the game contains multiple rounds of strategic interactions, backward induction is applied to ensure subgame perfection. In the fourth stage, when the supervisor learns poor quality, their collective profits in a collusion-free context are $-\beta$. Instead, their collective profits in a collusive context are $-\xi(\varphi_c + \beta + \varphi_s)$. To prevent collusion, the incentive mechanism should satisfy $-\beta \geq -\xi(\varphi_c + \beta + \varphi_s)$. Therefore, the collusion-proof constraint is given by

$$\xi(\varphi_c + \varphi_s) - (1 - \xi)\beta \geq 0 \tag{10}$$

in the third stage, given the collusion-proof constraint (10), the contractor decides on the quality effort e to maximize expected payoffs Π_{CG}^c. The contractor's expected payoffs Π_{CG}^c include the contract price t, construction costs ce^2, expected penalties $(1-e)[p+(1-p)\xi]\beta$ imposed by the owner, and expected fines $(1-e)(1-p)\xi\varphi_c$ collected by the government. Thus, the contractor's expected payoffs are $\Pi_{CG}^c = t - ce^2 - (1-e)[p + (1-p)\xi]\beta - (1-e)(1-p)\xi\varphi_c$. Therefore, the contractor's incentive compatibility constraint is given as follows.

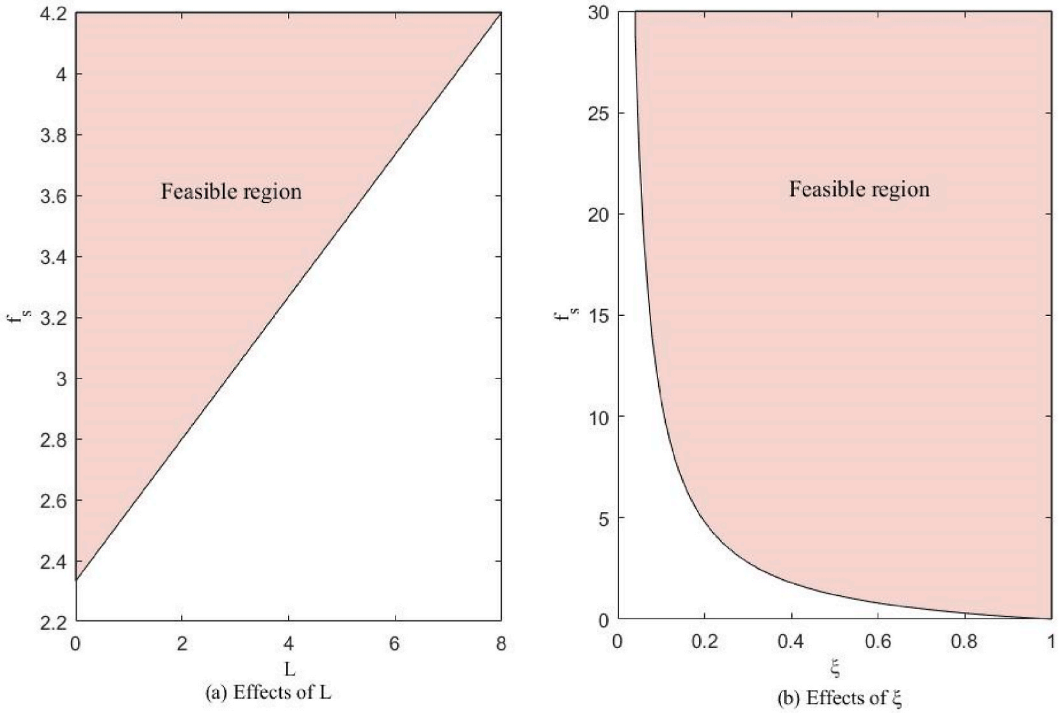


Fig. 7. Effects of different parameters on f_s when $Q_h = 1, Q_l = 0, c = 0.6, \eta = 0.1$.

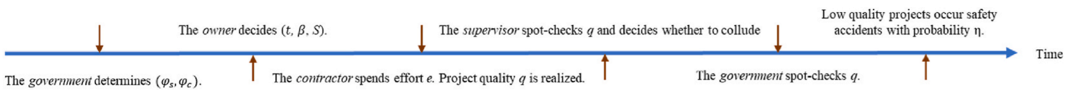


Fig. 8. The sequence of events for general projects with collusion.

$$e = \underset{e}{\operatorname{argmax}} \Pi^c_{CG} \tag{11}$$

in the second stage, given equation (11), the owner determines the contract price t, penalty term β, and supervision fees S to maximize its expected payoffs, which are $\Pi^c_{OG} = eQ_h + (1-e)Q_l - t - S + (1-e)[p + (1-p)\xi]\beta$. To ensure the agents join in the contract, their individual rationality constraints should be satisfied, which are $\Pi^c_{CG} \geq 0$, $\Pi^c_{SG} = S - (1-e)(1-p)\xi\varphi_s \geq 0$. Therefore, the owner's optimization programming is described as

$$\begin{aligned} &\max_{e\in[0,1],t,S\geq 0,\beta\in[0,\Omega]} \Pi^c_{OG} \\ \text{Subject to} \quad &\Pi^c_{CG} \geq 0, \Pi_{SG} \geq 0, \\ &e = \arg\max_e \Pi^c_{CG} \end{aligned} \tag{12}$$

Solving the above optimization programming (12) derives the equilibrium outcomes summarized in Lemma 3.

Lemma 3. ***The optimal construction contracts provided by the owner are given by:***

	Owner	***Contractor***
When $\Omega \geq \frac{\Delta + (1-p)\xi\varphi_s}{p + (1-p)\xi}$,	$\beta = \frac{\Delta + (1-p)\xi\varphi_s}{p + (1-p)\xi}$, $t = \frac{\Delta + (1-p)\xi(\varphi_c+\varphi_s)}{4c}[4c - \Delta - (1-p)\xi(\varphi_c + \varphi_s)]$, $S = \left(1 - \frac{\Delta + (1-p)\xi(\varphi_c+\varphi_s)}{2c}\right)(1-p)\xi\varphi_s$.	$e = \frac{\Delta + (1-p)\xi(\varphi_c+\varphi_s)}{2c}$.
When $\Omega < \frac{\Delta + (1-p)\xi\varphi_s}{p + (1-p)\xi}$,	$\beta = \Omega$, $t = \frac{X(4c - X)}{4c}$, *where* $X = [p + (1-p)\xi]\Omega + (1-p)\xi\varphi_c$. $S = \left(1 - \frac{X}{2c}\right)(1-p)\xi\varphi_s$.	$e = \frac{X}{2c}$.

In the first stage, the government's expected payoffs are $\Pi^c_{GG} = (1-e)(1-p)\xi(\varphi_c + \varphi_s) - (1-e)\eta L$. The government aims to maximize the expected payoffs of the construction system, which are $\Pi^c_{SY} = \Pi^c_{OG} + \Pi^c_{SG} + \Pi^c_{CG} + \Pi^c_{GG} = eQ_h + (1-e)Q_l - ce^2 - (1-e)\eta L$. Therefore, the government's optimization problem can be described as

$$\begin{aligned} &\max_{\varphi_c,\varphi_s} \Pi^c_{SY} = eQ_h + (1-e)Q_l - ce^2 - (1-e)\eta L. \\ \text{Subject to} \quad &\xi(\varphi_c + \varphi_s) - (1-\xi)\beta \geq 0. \end{aligned} \tag{13}$$

By solving the above optimization programming (13), Corollary 4 summarizes the equilibriums outcomes.

Corollary 4. *When general projects face the threat of collusion, in equilibrium:*

When $\eta L \geq \frac{(1-p)(1-\xi)\Delta}{p + (1-p)\xi}$,	***The equilibrium is the same as that without collusion.***	
When $\eta L < \frac{(1-p)(1-\xi)\Delta}{p + (1-p)\xi}$,	*Government*	$\varphi_c = \begin{cases} \frac{\Delta + \eta L - [p + (1-p)\xi]\Omega}{(1-p)\xi}, & \Omega \leq \frac{\eta L}{(1-\xi)(1-p)} \\ \frac{[2(1-p)(1-\xi) - 1]\eta L + (1-p)(1-\xi)\Delta}{\xi(1-\xi)(1-p)^2}, & \text{otherwise} \end{cases}$, $\varphi_s = \begin{cases} \frac{\Omega - \Delta - \eta L}{(1-p)\xi}, & \Omega \leq \frac{\eta L}{(1-\xi)(1-p)} \\ \frac{[p + (1-p)\xi]\eta L - (1-p)(1-\xi)\Delta}{\xi(1-\xi)(1-p)^2}, & \text{otherwise} \end{cases}$.
	Owner	$\beta = \begin{cases} \Omega, & \Omega \leq \frac{\eta L}{(1-\xi)(1-p)} \\ \frac{\eta L}{(1-\xi)(1-p)}, & \text{otherwise} \end{cases}$, $t = \frac{(\Delta + \eta L)(4c - \Delta - \eta L)}{4c}$, $S = \begin{cases} \frac{(2c - \Delta - \eta L)(\Omega - \Delta - \eta L)}{2c}, & \Omega \leq \frac{\eta L}{(1-\xi)(1-p)} \\ \frac{(2c - \Delta - \eta L)\{[p + (1-p)\xi]\eta L - (1-p)(1-\xi)\Delta\}}{2c(1-\xi)(1-p)}, & \text{othwewise} \end{cases}$.
	Contractor	$e = \begin{cases} \frac{\Delta + \eta L}{2c}, & \eta L \leq 2c - \Delta \\ 1, & \text{otherwise} \end{cases}$.

When the social welfare losses are relatively high (case i), the government can impose extremely high fines, which force the contractor to give up colluding with the corrupt supervisor. Therefore, the collusion-proof constraint is not binding. Instead, when the social welfare losses are relatively low (case ii), colluding with the supervisor becomes profitable for the contractor. Therefore, the government should determine the fines that satisfy the collusion-proof constraint. The proof of Corollary 4in Appendixes has shown that any fines that cannot make the collusion-proof contract binding will decrease the construction system's expected payoffs. The reason is that the severe fines will cause over-incentive problems. Therefore, the collusion-proof constraint should keep binding under such a circumstance.

Proposition 4. *If $\eta L \leq (1-p)(1-\xi)\Omega$, the owner's expected payoffs Π^c_{OG} increase in L. Otherwise, Π^c_{OG} decrease.*

In zone I ($\eta L > (1-p)(1-\xi)\Omega$), the expensive social welfare losses make the government induce the contractor to spend more effort than the value the owner prefers. Hence, the owner's expected payoffs Π^c_{OG} decrease. Instead, in zone II ($\eta L \leq (1-p)(1-\xi)\Omega$), the marginal benefits exceed the marginal costs. Hence, the owner's expected payoffs Π^c_{OG} increase. By contrast, in zone III ($\eta L \geq (1-p)(1-\xi)\Delta/[p+(1-p)\xi]$), the fines are so high that the contractor gives up colluding with the supervisor. Finally, in zone IV, the social welfare losses are so expensive that the government induces the contractor to exert an effort equal to one. The graphical illustration is given in Fig. 9.

5. Implications

The optimal government regulation strategies are derived through the above analysis. Based on the developed game model and the derived equilibrium outcomes, several novel managerial implications are further proposed to analyze the effects of government regulation on construction projects under threat of unethical opportunistic behaviors.

Corollary 5. The government can benefit from regulation at the expense of the owner's interests.

Undoubtedly, the presence of opportunistic behaviors generates adverse effects for the owner. To prevent these unethical behaviors, the government penalizes the supervisor and contractor for failing to fulfill their duties. However, the shock or noise during the construction and supervision process exposes the contractor and supervisor to additional risks. The incurred losses should be compensated by the project owner. Otherwise, they will refuse to participate in the construction and supervision contracts. The government collects these penalties from the contractor and the supervisor, thereby reaping benefits from regulating such unethical opportunistic behaviors at the expense of owners' interests. Therefore, the owner may discontinue the procurement of high-risk construction projects under certain circumstances.

Corollary 6. Government regulation can achieve systemic optimality.

Under government regulations, the contractor's optimal quality efforts in different equilibriums are equal to $\frac{\Delta+\eta L}{2c}$, which means the government can make the system achieve optimal outcomes. The intuitive explanation is that since government regulation is executive action [55], the government can take not only monetary fines but also non-monetary penalties in the implementation process, such as reduced qualifications or imprisonment. The government can implement sufficiently high incentives to deter opportunistic behaviors in construction projects effectively. Therefore, the government can induce the contractor to spend an optimal effort that maximizes the expected payoffs of the system.

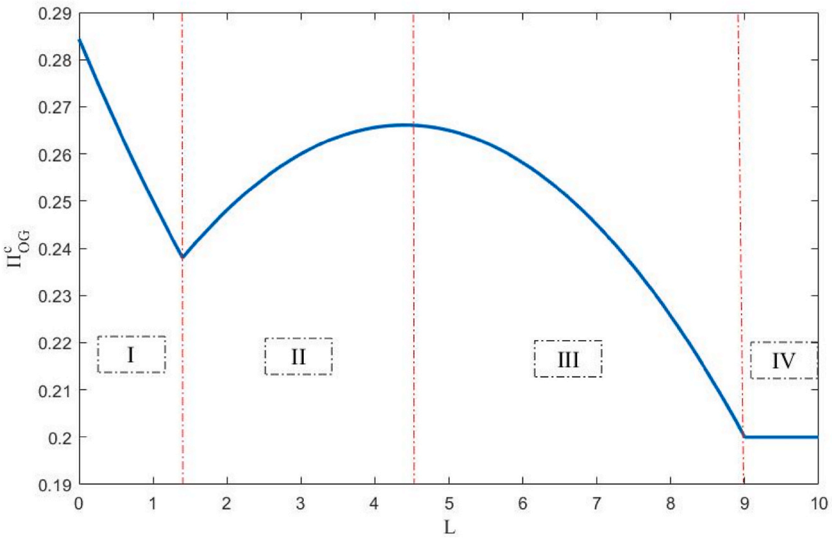


Fig. 9. Effects of Ω on Π^c_{OG} when $\Delta = 0.7, c = 0.8, p = 0.6, \xi = 0.3, \eta = 0.1, \Omega = 0.5$.

Corollary 7. Government regulation may hurt the interests of the owner in some cases.

The government aims to maximize the interests of the system, while the owner seeks to maximize their own self-interests. When the contractor has a relatively low liability, government regulation can compel the contractor to exert more effort. Both the owner and government benefit from incentivizing greater effort. While the contractor has a relatively high liability, the owner intends to induce the contractor to spend an effort equal to $\frac{\Delta}{2c}$, but the government wants to induce an effort equal to $\frac{\Delta+\eta L}{2c}$. Increasing effort will result in the owner transferring more payments to the contractor for construction projects. Therefore, government regulations can cause losses for owners in such situations

Corollary 8. Government regulation reduces the risks of occurring accidents to $\left(1-\min\left\{\frac{\Delta+\eta L}{2c},1\right\}\right)\eta$.

The government aims to maximize the expected payoffs of the system rather than completely eliminating security risks, as doing so would be prohibitively expensive and could hinder growth in the construction industry. As Corollary 5 shows, the owner may choose not to undertake projects due to the indirect burden of exorbitant fines. Furthermore, this corollary implies that projects with high profitability or the potential to generate significant social welfare losses are less likely to experience safety accidents, while those with high production costs are more prone to such incidents. These findings can offer valuable and helpful guidance for enhancing government supervision of construction projects.

Corollary 9. General projects are more susceptible to opportunistic behaviors than dominant ones.

Although dominant projects play a decisive role in safety, health, environmental protection, and public interest, the present supervision system in the construction industry exposes general projects to more severe information asymmetry. The existence of a construction supervisor ensures informational symmetry in dominant projects. In contrast, imperfect supervision technology results in an asymmetrical information context for general projects. Corollary 5 demonstrates that despite the government's ability to prevent opportunistic behaviors, the owner still suffers additional losses. Therefore, general projects are more susceptible to opportunistic behaviors than dominant ones, which emphasizes the owner's need for the strengthened supervision management of general construction projects.

6. Discussion

In this study, we investigate optimal government regulation strategies for inhibiting different opportunistic behaviors in construction projects and propose several novel managerial implications to analyze the effects of government regulation on construction projects. Consistent with previous studies of government regulation [14,15], our findings demonstrate that the government can play a significant role in regulating opportunistic behaviors. Especially government regulation can achieve systemic optimality. However, it should be noted that government interventions through regulation may not always align with the interests of owners and could potentially harm them in certain cases. There are two intuitive explanations for this phenomenon. First, according to Corollary 5, the supervisor and the contractor may be held accountable for certain risks arising from environmental factors or imperfect supervision technology [49], which will ultimately fall upon the owner. Second, as Corollary 7 reveals, the project owner and government may have conflicting interests. Based on the above analysis, we can deduce that the owner may refrain from purchasing or producing construction projects under certain circumstances, such as those with high risk or low profitability. This outcome could potentially adversely affect the robust growth of the whole construction industry.

Moreover, deviating from prior research that emphasizes the principal's responsibility in designing incentive mechanisms or contracts to mitigate opportunistic behaviors, this paper underscores the regulatory role of government. The reasons for this shift are threefold. Firstly, due to the intricate nature of construction, the diverse range of skills required, and the sheer scale of some projects, combined with lengthy execution periods, it presents a challenge for those without an understanding of construction processes and procedures to effectively control and manage the construction process [56]. The owner's specialized knowledge and skills are comparatively inferior to those of the government's specially designated inspection agency. Secondly, since the agents hired by the owner are generally protected by their liabilities, the owner cannot offer additional incentives beyond liability [35]. In contrast, the government is not bound by this constraint and can provide more diverse incentives [22,23], such as non-monetary ones like imprisonment. Thirdly, the owner may not always desire the quality requirements set by the government, which could lead to a lack of motivation to prevent opportunistic behaviors. However, contrary to existing studies that suggest such behaviors can reduce contractor efficiency, our findings show that government regulation can facilitate first-best outcomes within the system. Therefore, this conclusion can provide strong support for government regulation.

Furthermore, there are still some necessary extensions that deserve further study. First, the supervision costs of the supervisor and the government are ignored in the study. What are the optimal regulation strategies if supervision costs exist? Second, what if the supervision unit on behalf of the government may also be selfish and opportunistic? And how to govern corruption? Finally, what if the owner may collude with the contractor to pursue more self-profits?

7. Conclusions

Opportunistic behaviors during construction can lead to poor quality construction projects and safety accidents, which call for government regulation on construction projects. Towards this end, this paper investigates optimal government regulation strategies to inhibit opportunistic behaviors in construction projects. A multi-stage dynamic game model with asymmetric information is developed to characterize multiplayers' strategic interactions. Two opportunistic behaviors are explored, i.e., the contractor's moral hazard and supervisor-contractor collusion. According to the characteristic of construction projects, the regulation problems are further divided into hidden information for general projects and hidden effort for dominant projects. This study explores the contractor's moral hazard scenarios wherein the supervisor is benevolent and always reports truthfully. In this case, the optimal fine (coefficient) to the contractor for failing to meet the requirements is derived. Subsequently, to manage the secret collusion between the supervisor and the contractor, the optimal fine (coefficient) for their failure to fulfill their responsibilities is determined. Subsequently, by analyzing the equilibrium outcomes, this study proposes several novel managerial implications to present the effects of government regulation on construction projects under threat of unethical opportunistic behaviors. This study provides theoretical support for government regulation on opportunistic behaviors in construction projects.

Data availability statements

The data used in this study is borrowed from a real construction project case, the project 'Sino-Singapore Eco-City' in Tianjin, China. More detailed data information about this project can be learned from the research of Chen &Li [57].

Funding statement

This research was funded by the the Sichuan Science and Technology Program (Grant No. 2023NSFSC1015), and the Doctoral Start-up Fund Project of North Sichuan Medical College (Grant No. CBY22-QDA20).
This research was funded by the the Sichuan Science and Technology Program (Grant No. 2023NSFSC1015), and the Doctoral Start-up Fund Project of North Sichuan Medical College (Grant No. CBY22-QDA20).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix I

Proof of Corollary 1.

Since the economic contractor can't benefit from spending more quality effort, the quality effort will not be more than e_0, i.e., $e = e_0$. Therefore, the fine coefficient f is

$$f = \begin{cases} 2ce_0 - \Omega, & for\ \Omega \le \Delta \\ 2ce_0 - \Delta, & for\ \Omega > \Delta \end{cases} \tag{A.1}$$

By substituting f, the optimization program can be transferred into the unconstrained optimization problem

$$\max_{e_0 \in (0,1)} \Pi_{SE} = e_0 Q_h + (1 - e_0) Q_l - ce_0^2 - (1 - e_0)\eta L \tag{A.2}$$

The first derivative of Π_{SE} to e_0 is

$$\frac{\partial \Pi_{SE}}{\partial e_0} = \Delta - 2ce + \eta L \tag{A.3}$$

Therefore, the standard quality effort is

$$e_0 = \begin{cases} \dfrac{\Delta + \eta L}{2c} & \eta L \le 2c - \Delta \\ 1 & \eta L > 2c - \Delta \end{cases} \tag{A.4}$$

By substituting e_0 into f, the optimal fine coefficient is

$$f = \begin{cases} \Delta + \eta L - \Omega, & for\ \Omega \le \Delta \\ \eta L, & for\ \Omega > \Delta \end{cases} \tag{A.5}$$

Proof of Corollary 2.

The first derivative of Π_{SG} to φ is

$$\frac{\partial \Pi_{SG}}{\partial \varphi} = [\Delta - 2ce + \eta L] \frac{\partial e}{\partial \varphi} \tag{A.6}$$

By substituting the owner's response into equation (6), the analysis is continued as follows.

i. When $\Omega \le \frac{\Delta}{p+(1-p)\xi}$, $\frac{\partial \Pi_{SG}}{\partial \varphi} = \frac{1-p}{2c}\xi[\Delta + \eta L - [p + (1 - p)\xi]\Omega - (1 - p)\xi\varphi]$. Thus, $\varphi = \frac{\Delta+\eta L-[p+(1-p)\xi]\Omega}{(1-p)\xi}$.

ii. When $\Omega \geq \frac{\Delta}{p+(1-p)\xi}$, $\frac{\partial e}{\partial \varphi} = \frac{(1-p)\xi}{2c}$, so $\frac{\partial \Pi_{SG}}{\partial \varphi} = \frac{1-p}{2c}\xi[\eta L - (1-p)\xi\varphi]$. Thus, the fines are $\varphi = \frac{\eta L}{(1-p)\xi}$.

Therefore, the optimal fines imposed by the government on the contractor is

$$\varphi = \begin{cases} \dfrac{\Delta + \eta L - [p + (1-p)\xi]\Omega}{(1-p)\xi}, & for\ \xi \leq \dfrac{\Delta - p\Omega}{(1-p)\Omega} \\ \dfrac{\eta L}{(1-p)\xi}, & for\ \xi > \dfrac{\Delta - p\Omega}{(1-p)\Omega} \end{cases} \tag{A.7}$$

Proof of Proposition 2.

The owner's expected payoffs can be rewritten as $\Pi_{OG} = eQ_h + (1-e)Q_l - ce^2 - (1-e)(1-p)\xi\varphi$. Therefore, the first derivative of Π_{OG} to L is

$$\frac{\partial \Pi_{OG}}{\partial L} = [\Delta - 2ce + (1-p)\xi\varphi]\frac{\partial e}{\partial L} - (1-e)(1-p)\xi\frac{\partial \varphi}{\partial L} \tag{A.8}$$

i. When $\Omega \geq \frac{\Delta}{p+(1-p)\xi}$, $\frac{\partial \Pi_{OG}}{\partial L} = -(1-e)(1-p)\xi\frac{\partial \varphi}{\partial L} \leq 0$.

ii. When $\Omega < \frac{\Delta}{p+(1-p)\xi}$, $\frac{\partial \Pi_{OG}}{\partial L} = \frac{\eta}{2c}\{2\Delta - 2c + \eta L - [p + (1-p)\xi]\Omega\}$.

That is, when $\eta L \leq 2c + [p + (1-p)\xi]\Omega - 2\Delta$, $\frac{\partial \Pi_{OG}}{\partial L} \leq 0$, otherwise, $\frac{\partial \Pi_{OG}}{\partial L} > 0$.

Proof of Corollary 3.

In the first stage, since collusion cannot be observed by the outsider, when the quality effort e is lower than the standard effort e_0, the fine coefficient for the contractor is

$$f_C = \begin{cases} 2ce_0 - \Omega, & for\ \Omega \leq \Delta \\ 2ce_0 - \Delta, & for\ \Omega > \Delta \end{cases} \tag{A.9}$$

thus, the optimal standard quality effort is given by

$$e_0 = \frac{\Delta + \eta L}{2c} \tag{A.10}$$

Substituting f_C and β into equation (8), the fine coefficient for the supervisor is

$$f_s \geq 2ce_0\left(\frac{1}{\xi} - 1\right) \tag{A.11}$$

For fear of abusing authority by the quality supervision station, the fine coefficient for the supervisor is

$$f_s = (\Delta + \eta L)\left(\frac{1}{\xi} - 1\right) \tag{A.12}$$

Proof of Corollary 4.

The first derivatives of Π_{SY}^c to β_c and β_s are

$$\frac{\partial \boldsymbol{\Pi}_{SY}^c}{\partial \boldsymbol{\varphi}_c} = (\Delta - \mathbf{2}\boldsymbol{ce} + \boldsymbol{\eta L})\frac{\partial \boldsymbol{e}}{\partial \boldsymbol{\varphi}_c} \tag{A.13}$$

$$\frac{\partial \boldsymbol{\Pi}_{SY}^c}{\partial \boldsymbol{\varphi}_s} = (\Delta - \mathbf{2}\boldsymbol{ce} + \boldsymbol{\eta L})\frac{\partial \boldsymbol{e}}{\partial \boldsymbol{\varphi}_s} \tag{A.14}$$

1) When the collusion-proof constraint is not binding,i.e., $\boldsymbol{\xi}(\boldsymbol{\varphi}_c + \boldsymbol{\varphi}_s) - (\mathbf{1} - \boldsymbol{\xi})\boldsymbol{\beta} > \mathbf{0}$.The government's mathematical optimization program can be transferred into an unconstrained optimization problem, which is the same as Section 4.2.Here we will not report it again and provide the equilibrium outcomes as follows.

$$\boldsymbol{\varphi}_c = \begin{cases} \dfrac{\Delta + \boldsymbol{\eta L} - [\boldsymbol{p} + (\mathbf{1} - \boldsymbol{p})\boldsymbol{\xi}]\boldsymbol{\Omega}}{(\mathbf{1} - \boldsymbol{p})\boldsymbol{\xi}}, & \boldsymbol{for\ \xi} \leq \dfrac{\Delta - \boldsymbol{p\Omega}}{(\mathbf{1} - \boldsymbol{p})\boldsymbol{\Omega}} \\ \dfrac{\boldsymbol{\eta L}}{(\mathbf{1} - \boldsymbol{p})\boldsymbol{\xi}}, & \boldsymbol{for\ \xi} > \dfrac{\Delta - \boldsymbol{p\Omega}}{(\mathbf{1} - \boldsymbol{p})\boldsymbol{\Omega}} \end{cases}, \boldsymbol{\varphi}_s = \mathbf{0} \tag{A.15}$$

since $\boldsymbol{\xi}(\boldsymbol{\varphi}_c + \boldsymbol{\varphi}_s) - (\mathbf{1} - \boldsymbol{\xi})\boldsymbol{\beta} > \mathbf{0}$, $\boldsymbol{\eta L} \geq \frac{(\mathbf{1}-\boldsymbol{p})(\mathbf{1}-\boldsymbol{\xi})\Delta}{\boldsymbol{p}+(\mathbf{1}-\boldsymbol{p})\boldsymbol{\xi}}$.

2) When the collusion-proof constraint is binding, i.e., $\xi(\varphi_c + \varphi_s) - (1 - \xi)\beta = 0$.

a) When $\Omega \geq \frac{\Delta+(1-p)\xi\varphi_s}{p+(1-p)\xi}$, $e = \frac{\Delta+(1-p)\xi(\varphi_c+\varphi_s)}{2c}$, $\beta = \frac{\Delta+(1-p)\xi\varphi_s}{p+(1-p)\xi}$.

$$\frac{\partial e}{\partial \varphi_s} = \frac{(1-p)^2\xi(1-\xi)}{2c[p+(1-p)\xi]} \geq 0 \tag{A.16}$$

$$\frac{\partial \Pi_{SY}^c}{\partial \varphi_s} = \left[\eta L - (1-p)(1-\xi)\frac{\Delta+(1-p)\xi\varphi_s}{p+(1-p)\xi}\right]\frac{\partial e}{\partial \varphi_s} \tag{A.17}$$

Therefore, the optimal fines for the supervisor are

$$\varphi_s = \frac{[p+(1-p)\xi]\eta L - (1-p)(1-\xi)\Delta}{\xi(1-\xi)(1-p)^2} \tag{A.18}$$

By substituting φ_s into the contractor's incentive compatibility constraint, the penalty terms are.

$$\beta = \frac{\eta L}{(1-p)(1-\xi)} \tag{A.19}$$

By substituting β into collusion-proof constraint, the fines for the contractor are.

$$\varphi_c = \frac{[2(1-p)(1-\xi)-1]\eta L + (1-p)(1-\xi)\Delta}{\xi(1-\xi)(1-p)^2} \tag{A.20}$$

since $\Omega \geq \frac{\Delta+(1-p)\xi\varphi_s}{p+(1-p)\xi}$, $\Omega \geq \frac{\Delta+(1-p)\xi\varphi_s}{p+(1-p)\xi} = \frac{\eta L}{(1-\xi)(1-p)}$.

$$\frac{\partial \Pi_{SY}^c}{\partial \varphi_c} = \{\Delta - [p+(1-p)\xi]\Omega - (1-p)\xi\beta_c + \eta L\}\frac{(1-p)\xi}{2c} \tag{A.21}$$

b) When $\Omega < \frac{\Delta+(1-p)\xi\varphi_s}{p+(1-p)\xi}$, $e = \frac{[p+(1-p)\xi]\Omega+(1-p)\xi\varphi_c}{2c}$, $\beta = \Omega$, $\frac{\partial e}{\partial \varphi_c} = \frac{(1-p)\xi}{2c} > 0$.

Thus, the fines for the contractor are

$$\varphi_c = \frac{\Delta + \eta L - [p+(1-p)\xi]\Omega}{(1-p)\xi} \tag{A.22}$$

By substituting φ_c into collusion-proof constraint, the fines for the supervisor are

$$\varphi_s = \frac{\Omega - \Delta - \eta L}{(1-p)\xi} \tag{A.23}$$

Proof of Proposition 4.

The owner's expected payoffs are rewritten as

$$\Pi_{OG}^c = eQ_h + (1-e)Q_l - ce^2 - (1-e)(1-p)(1-\xi)\beta \tag{A.24}$$

The first derivative is

$$\frac{\partial \Pi_{OG}^c}{\partial L} = [\Delta - 2ce + (1-p)(1-\xi)\beta]\frac{\partial e}{\partial L} - (1-e)(1-p)(1-\xi)\frac{\partial \beta}{\partial L} \tag{A.25}$$

i. When $\Omega \geq \frac{\eta L}{(1-p)(1-\xi)}$, $\beta = \frac{\eta L}{(1-p)(1-\xi)}$, $e = \frac{\Delta+\eta L}{2c}$, $\frac{\partial \Pi_{OG}^c}{\partial L} = -(1-e)\eta < 0$.

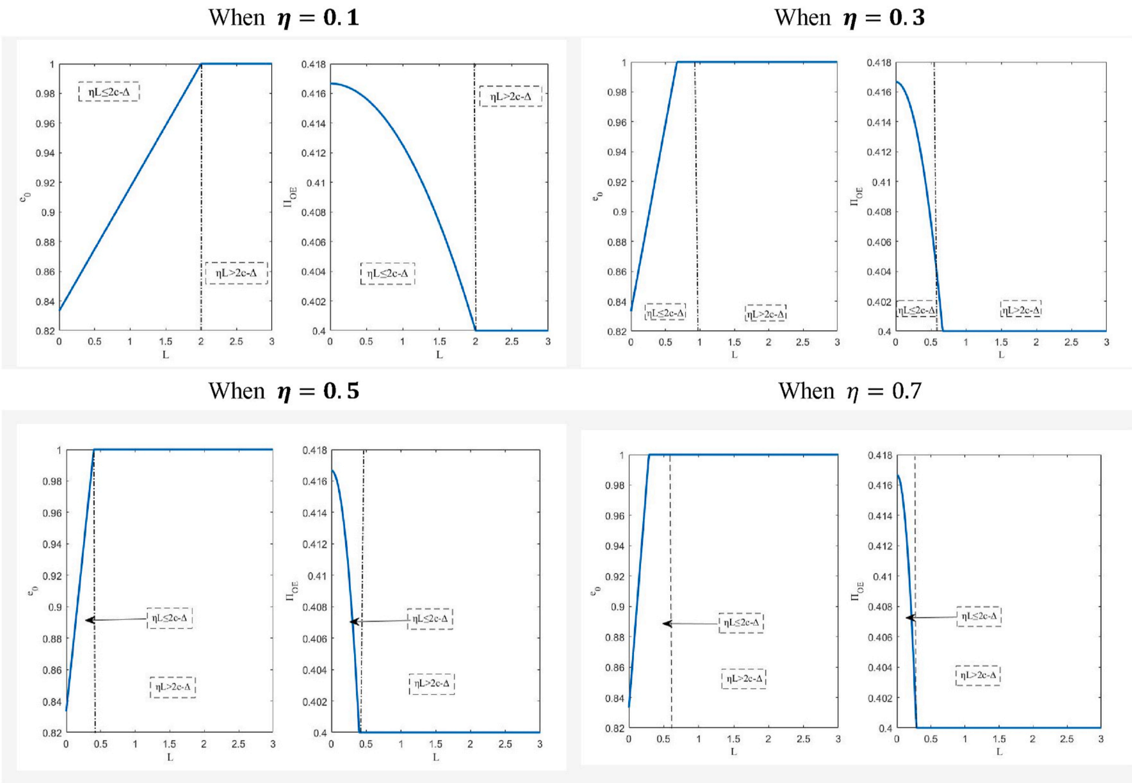
ii. When $\Omega < \frac{\eta L}{(1-p)(1-\xi)}$, $\beta = \Omega$, $e = \frac{[p+(1-p)\xi]\Omega+(1-p)\xi\varphi_c}{2c} = \frac{\Delta+\eta L}{2c}$, $\frac{\partial \Pi_{OG}^c}{\partial L} = [-\eta L + (1-p)(1-\xi)\Omega]\frac{\eta}{2c}$.

Appendix II

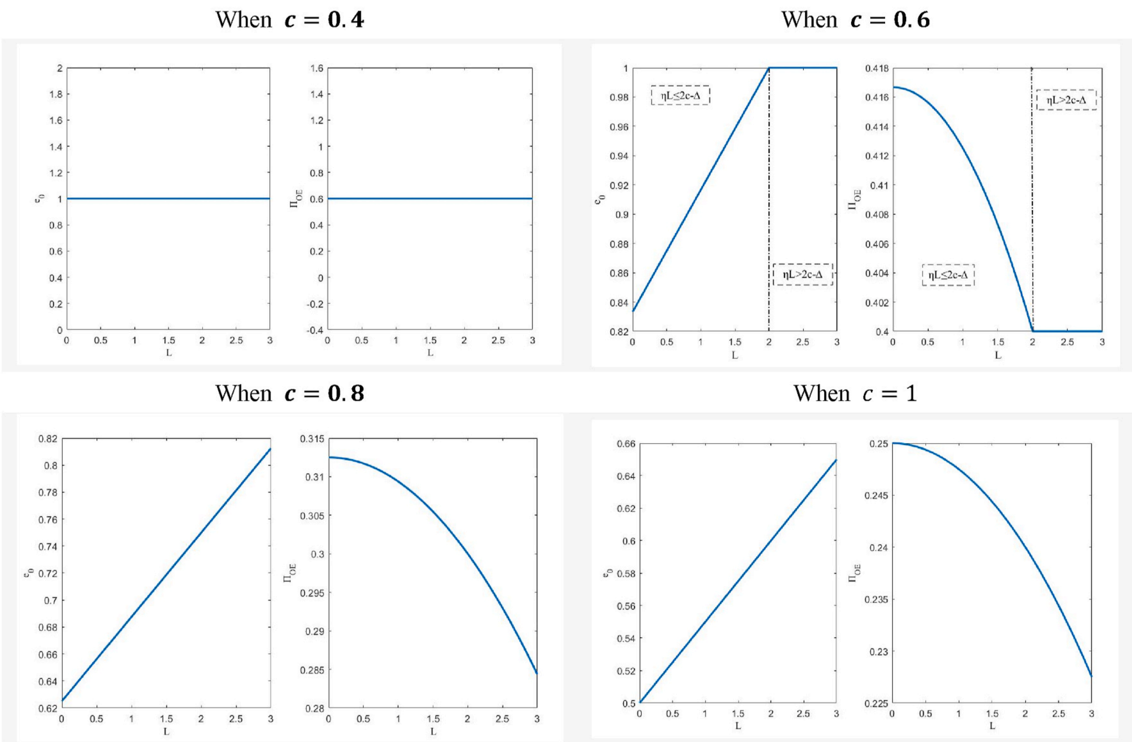
Here, we perform a sensitivity analysis to establish that any variations in parameters do not affect the conclusions.

The verification of Proposition 1

The effects of η



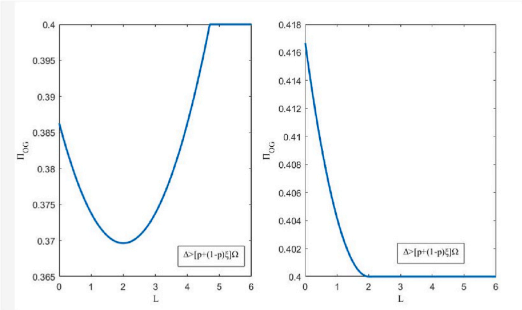
The effects of c

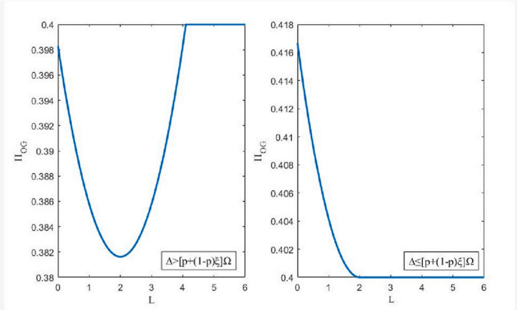


The verification of Proposition 2

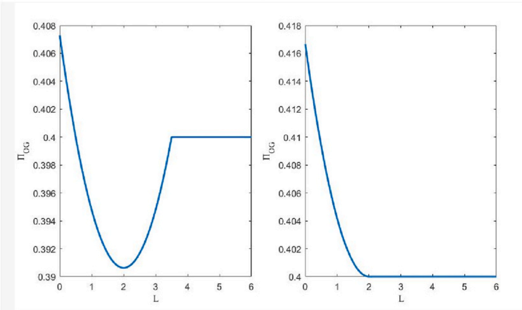
The effects of ξ

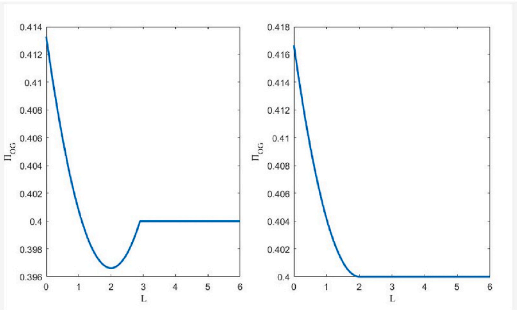
When $\boldsymbol{\xi} = \mathbf{0.1}$ When $\boldsymbol{\xi} = \mathbf{0.3}$





When $\boldsymbol{\xi} = \mathbf{0.5}$ When $\xi = 0.7$

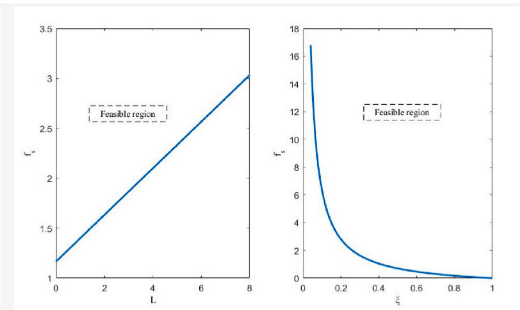


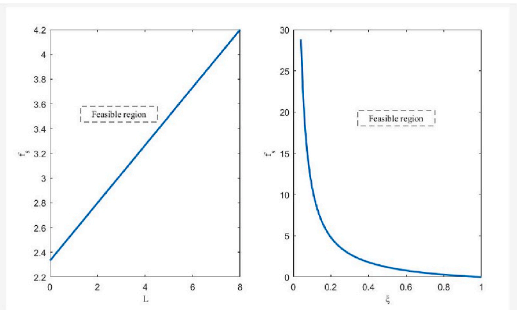


The verification of Proposition 3

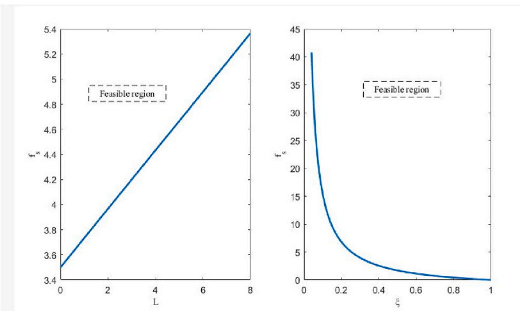
The effects of Δ

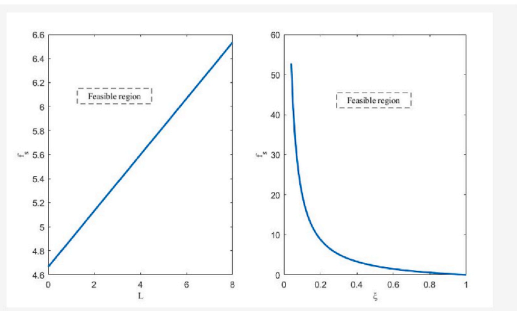
When $\Delta = \mathbf{0.5}$ When $\Delta = \mathbf{1}$





When $\Delta = \mathbf{1.5}$ When $\Delta = 2$

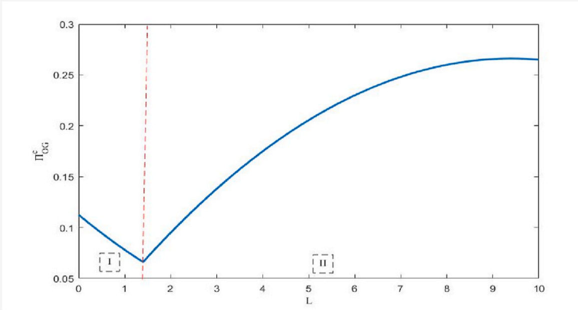




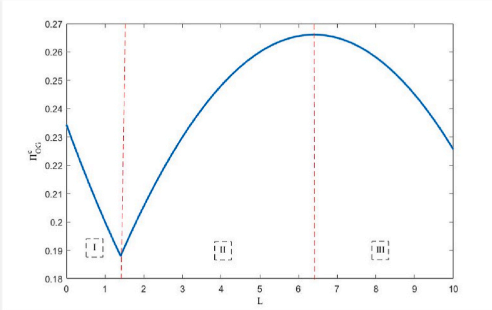
The verification of Proposition 4

The effects of Δ.

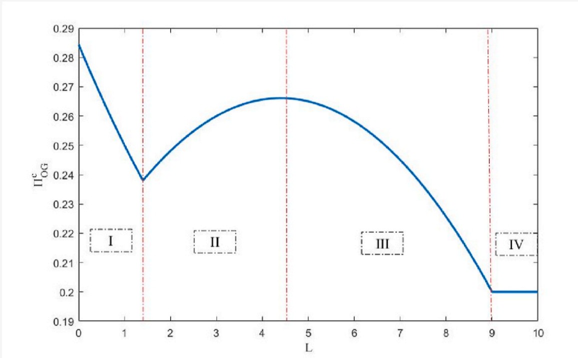
When Δ= **0.2**



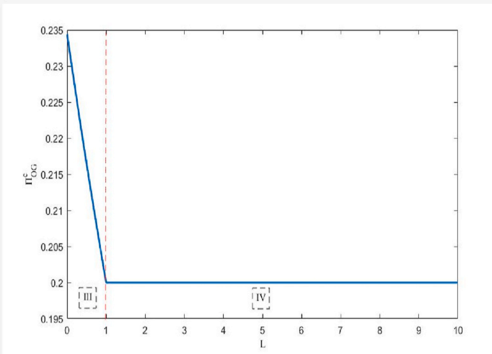
When Δ= **0.5**



When Δ= **0.7**

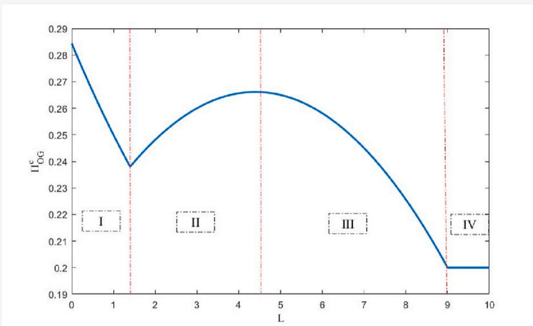


When Δ= 1.5

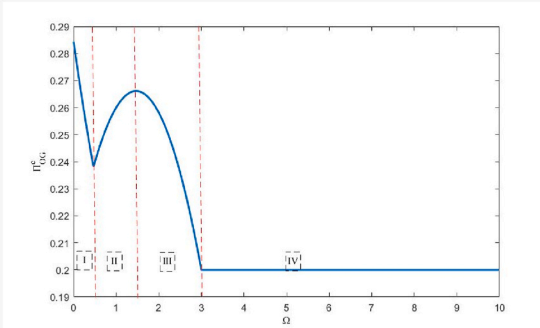


The effects of η.

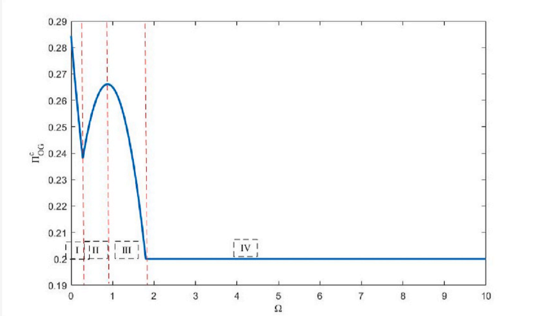
When $\boldsymbol{\eta} = \mathbf{0.1}$



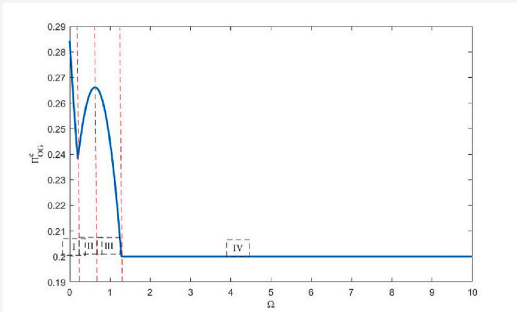
When $\boldsymbol{\eta} = \mathbf{0.3}$



When $\boldsymbol{\eta} = \mathbf{0.5}$



When $\eta = 0.7$



References

[1] M.Z. Shanti, C.-S. Cho, B.G. de Soto, Y.-J. Byon, C.Y. Yeun, T.Y. Kim, Real-time monitoring of work-at-height safety hazards in construction sites using drones and deep learning, J. Saf. Res. 83 (2022) 364–370, https://doi.org/10.1016/j.jsr.2022.09.011.
[2] M. Alkaissy, M. Arashpour, B. Ashuri, Y. Bai, R. Hosseini, Safety management in construction: 20 years of risk modeling, Saf. Sci. 129 (2020), 104805, https://doi.org/10.1016/j.ssci.2020.104805.
[3] C. Kenny, Transport construction, corruption and developing countries, Transp Rev 29 (2009) 21–41, https://doi.org/10.1080/01441640802075760.
[4] P.E.D. Love, L.A. Ika, J. Matthews, W. Fang, Curbing poor-quality in large-scale transport infrastructure projects, IEEE Trans. Eng. Manag. 69 (2022) 3171–3183, https://doi.org/10.1109/TEM.2020.3031890.
[5] C. Su, M. Wang, Quality incentive contract design in government procurement for innovation, Manag. Decis. Econ. 43 (2022) 1–20, https://doi.org/10.1002/mde.3621.
[6] J. Mullen, Investigating factors that influence individual safety behavior at work, J. Saf. Res. 35 (2004) 275–285, https://doi.org/10.1016/j.jsr.2004.03.011.
[7] Q. He, S. Dong, T. Rose, H. Li, Q. Yin, D. Cao, Systematic impact of institutional pressures on safety climate in the construction industry, Accid. Anal. Prev. 93 (2016) 230–239, https://doi.org/10.1016/j.aap.2015.11.034.
[8] C.K.H. Hon, A.P.C. Chan, M.C.H. Yam, Determining safety climate factors in the repair, maintenance, minor alteration, and addition sector of Hong Kong, J. Construct. Eng. Manag. 139 (2013) 519–528, 10.1061(asce)co.1943-7862.0000588.
[9] H. Abdul-Rahman, C. Wang, X.W. Yap, How professional ethics impact construction quality: perception and evidence in a fast developing economy, Sci. Res. Essays 5 (2010) 3742–3749.
[10] A. Cerić, Strategies for minimizing information asymmetries in construction projects: project managers' perceptions, J. Bus. Econ. Manag. 15 (2014) 424–440, https://doi.org/10.3846/16111699.2012.720601.
[11] P. Xiang, J. Zhou, X. Zhou, K. Ye, Construction project risk management based on the view of asymmetric information, J. Construct. Eng. Manag. 138 (2012) 1303–1311, https://doi.org/10.1061/(asce)co.1943-7862.0000548.
[12] P. Xiang, X. Huo, L. Shen, Research on the phenomenon of asymmetric information in construction projects - the case of China, Int. J. Proj. Manag. 33 (2015) 589–598, https://doi.org/10.1016/j.ijproman.2014.10.007.
[13] S. Ming, C. C.A.P, L. Yun, H. Yi, X. Bo, Understanding collusive practices in Chinese construction projects, J. Prof. Issues Eng. Educ. Pract. 143 (2017), 05016012, https://doi.org/10.1061/(ASCE)EI.1943-5541.0000314.
[14] B.T. Zhong, L.Y. Ding, H.B. Luo, Y. Zhou, Y.Z. Hu, H.M. Hu, Ontology-based semantic modeling of regulation constraint for automated construction quality compliance checking, Autom. ConStruct. 28 (2012) 58–70, https://doi.org/10.1016/j.autcon.2012.06.006.
[15] Q. Jiang, The optimal regulation on construction industry in China, in: Proceedings of the 2016 International Symposium on Business Cooperation and Development, Atlantis Press, 2016, pp. 337–341, https://doi.org/10.2991/isbcd-16.2016.70.
[16] N. Xia, Q. Xie, M.A. Griffin, G. Ye, J. Yuan, Antecedents of safety behavior in construction: a literature review and an integrated conceptual framework, Accid. Anal. Prev. 148 (2020), 105834, https://doi.org/10.1016/j.aap.2020.105834.
[17] Y. Chen, Q. Zeng, X. Zheng, B. Shao, L. Jin, Safety supervision of tower crane operation on construction sites: an evolutionary game analysis, Saf. Sci. 152 (2022), 105578, https://doi.org/10.1016/j.ssci.2021.105578.
[18] Q. Liu, X. Li, M. Hassall, Evolutionary game analysis and stability control scenarios of coal mine safety inspection system in China based on system dynamics, Saf. Sci. 80 (2015) 13–22, https://doi.org/10.1016/j.ssci.2015.07.005.
[19] R. Elvik, Speed enforcement in Norway: testing a game-theoretic model of the interaction between drivers and the police, Accid. Anal. Prev. 84 (2015) 128–133, https://doi.org/10.1016/j.aap.2015.08.017.
[20] Y. Luo, An organizational perspective of corruption, Manag. Organ. Rev. 1 (2005) 119–154, https://doi.org/10.1111/j.1740-8784.2004.00006.x.
[21] R. Signor, P.E.D. Love, L.A. Ika, White collar crime: unearthing collusion in the procurement of infrastructure projects, IEEE Trans. Eng. Manag. 69 (2022) 1932–1943, https://doi.org/10.1109/TEM.2020.2994636.
[22] R. Imrie, The role of the building regulations in achieving housing quality, Environ. Plann. Plann. Des. 31 (2004) 419–437, https://doi.org/10.1068/b3056.
[23] N. Raynsford, Sustainable construction: the Government's role, Proc. Inst. Civ. Eng.: Civil Engineering 138 (2000) 16–22, https://doi.org/10.1680/cien.2000.138.6.16.
[24] M.A.A. Mansour, S.D.A. Khadar, I.I.A. Falqi, Analyzing the implementation of environmental laws in the Saudi Arabian construction industry, Appl. Ecol. Environ. Res. 17 (2019) 3781–3802.
[25] L. Yu, H.T. Zhou, W. Zeng, Dynamic analysis of evolutionary game in project collusion control based on system dynamics model, J. Wuhan Univ. Technol. (Inf. Manag. Eng.) 37 (2015) 349–353.
[26] G.S. Yang, X.Y. Lu, Y. Xu, Simulation on rate of unannounced inspection for government investment project quality based on SD evolutionary game model, Science and Technology Management Research 38 (2018) 212–219.
[27] P.E.D. Love, P. Teo, B. Carey, C.-P. Sing, F. Ackermann, The symbiotic nature of safety and quality in construction: incidents and rework non-conformances, Saf. Sci. 79 (2015) 55–62, https://doi.org/10.1016/j.ssci.2015.05.009.
[28] W. John, H. Christofer, R. H.M, R. Sathyanarayanan, Relationship between construction safety and quality performance, J. Construct. Eng. Manag. 139 (2013), 04013003, https://doi.org/10.1061/(ASCE)CO.1943-7862.0000732.
[29] S.A. Lippman, K.F. McCardle, C.S. Tang, Using Nash bargaining to design project management contracts under cost uncertainty, Int. J. Prod. Econ. 145 (2013) 199–207, https://doi.org/10.1016/j.ijpe.2013.04.036.
[30] Z. Chen, Y. Lan, R. Zhao, C. Shang, Deadline-based incentive contracts in project management with cost salience, Fuzzy Optim. Decis. Making 18 (2019) 451–473, https://doi.org/10.1007/s10700-019-09302-y.
[31] J. Han, A. Rapoport, P.S.W. Fong, Incentive structures in multi-partner project teams, Engineering, Construction and Architectural Management 27 (2020) 49–65, https://doi.org/10.1108/ECAM-09-2018-0410.
[32] L. Shi, Y. He, M. Onishi, K. Kobayashi, Double moral hazard and risk-sharing in construction projects, IEEE Trans. Eng. Manag. 68 (2021) 1919–1929, https://doi.org/10.1109/TEM.2019.2938261.
[33] L.P. Kerkhove, M. Vanhoucke, A parallel multi-objective scatter search for optimising incentive contract design in projects, Eur. J. Oper. Res. 261 (2017) 1066–1084, https://doi.org/10.1016/j.ejor.2017.02.043.
[34] Y. Zhang, L. Xu, Quality incentive contract design in government procurement of public services under dual asymmetric information, Manag. Decis. Econ. 42 (2021) 34–44, https://doi.org/10.1002/mde.3211.
[35] L. Cui, Collusion governance strategies under the construction supervision system in China, Construct. Manag. Econ. (2023) 1–15, https://doi.org/10.1080/01446193.2023.2196431.
[36] S.Z.S. Tabish, K.N. Jha, The impact of anti-corruption strategies on corruption free performance in public construction projects, Construct. Manag. Econ. 30 (2012) 21–35, https://doi.org/10.1080/01446193.2011.654128.
[37] M. Jaraiedi, R.W. Plummer, M.S. Aber, Incentive/disincentive guidelines for highway construction contracts, J. Construct. Eng. Manag. 121 (1995) 112–120, https://doi.org/10.1061/(asce)0733-9364, 1995)121:1(112.
[38] X. Meng, B. Gallagher, The impact of incentive mechanisms on project performance, Int. J. Proj. Manag. 30 (2012) 352–362, https://doi.org/10.1016/j.ijproman.2011.08.006.
[39] J. Zhu, M. Hertogh, J. Zhang, Q. Shi, Z. Sheng, Incentive mechanisms in mega project-risk management considering owner and insurance Company as principals, J. Construct. Eng. Manag. 146 (2020), 04020120, https://doi.org/10.1061/(asce)co.1943-7862.0001915.
[40] C. Gao, T.C.E. Cheng, H. Shen, L. Xu, Incentives for quality improvement efforts coordination in supply chains with partial cost allocation contract, Int. J. Prod. Res. 54 (2016) 6216–6231, https://doi.org/10.1080/00207543.2016.1191691.
[41] J. Tirole, Hierarchies and bureaucracies: on the role of collusion in organizations, J. Law Econ. Organ. 2 (1986) 181–214, https://doi.org/10.2307/765048.

[42] R. Strausz, Delegation of monitoring in a principal-agent relationship, Rev. Econ. Stud. 64 (1997) 337–357, https://doi.org/10.2307/2971717.
[43] A. Faure-Grimaud, J.J. Laffont, D. Martimort, Collusion, delegation and supervision with soft information, Rev. Econ. Stud. 70 (2003) 253–279, https://doi.org/10.1111/1467-937X.000244.
[44] Kouroche Vafaï, Collusion and organization design, Economica 72 (2005) 17–37.
[45] F. Khalil, J. Lawarrée, S. Yun, Bribery versus extortion: allowing the lesser of two evils, Rand J. Econ. 41 (2010) 179–198, https://doi.org/10.1111/j.1756-2171.2009.00095.x.
[46] J. Ortner, S. Chassang, Making corruption harder: asymmetric information, collusion, and crime, J. Polit. Econ. 126 (2018) 2108–2133, https://doi.org/10.1086/699188. https://EconPapers.repec.org/RePEc:ucp:jpolec.
[47] Y. Wu, Y. Huang, W. Luo, C. Li, Construction supervision mechanism for public projects in China: progress goal–oriented perspective, J. Manag. Eng. 30 (2014) 205–213, https://doi.org/10.1061/(asce)me.1943-5479.0000179.
[48] M.M. Ting, Whistleblowing, American Political Science Review 102 (2008) 249–267, https://doi.org/10.1017/S0003055408080192.
[49] S.M. Hosseinian, D.G. Carmichael, Optimal incentive contract with risk-neutral contractor, J. Construct. Eng. Manag. 139 (2013) 899–909, https://doi.org/10.1061/(asce)co.1943-7862.0000663.
[50] H.M.E. Abdelsalam, M.M. Gad, Cost of quality in Dubai: an analytical case study of residential construction projects, Int. J. Proj. Manag. 27 (2009) 501–511, https://doi.org/10.1016/j.ijproman.2008.07.006.
[51] T.J. Kelleher, T.E. Abernathy, H.J. Bell, S.L. Reed, G.F. Hain, D.P. Hibshman, Y. Lisa Colon Herron Ramsey Kazem, S.J. Kelleher, L.N. Ortiz, D.L. Tabeling, M. S. Wierman, Smith, Currie & Hancock's Federal Government Construction Contracts: A Practical Guide for the Industry Professional, second ed., 2010, https://doi.org/10.1002/9780470549117.
[52] P. Yung, L.W.C. Lai, Supervising for quality: an empirical examination of institutional arrangements in China's construction industry, Construct. Manag. Econ. 26 (2008) 723–737, https://doi.org/10.1080/01446190801998690.
[53] K. Vafaï, Collusion and organization design, Economica 72 (2005) 17–37. http://www.jstor.org/stable/3548929.
[54] Y. Le, M. Shan, A.P.C. Chan, Y. Hu, Overview of corruption research in construction, J. Manag. Eng. 30 (2014), 02514001, https://doi.org/10.1061/(asce)me.1943-5479.0000300.
[55] H.D. Guo, S.W. Cui, Y.X. Zhang, E.H. Hao, X.P. Yang, The Governmental Supervision Responsibility and Standardization Construction of Construction Quality, Adv Mat Res (2013) 732–737, https://doi.org/10.4028/www.scientific.net/AMR.734-737.3370.
[56] B. Sichombo, M. Muya, W. Shakantu, C. Kaliba, The need for technical auditing in the Zambian construction industry, Int. J. Proj. Manag. 27 (2009) 821–832, https://doi.org/10.1016/j.ijproman.2009.02.001.
[57] W. Chen, L. Li, Incentive contracts for green building production with asymmetric information, Int. J. Prod. Res. 59 (2021) 1860–1874, https://doi.org/10.1080/00207543.2020.1727047.