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REPEATED GAME BEHAVIOR BETWEEN BIDDER AND REGULATORY AGENCY OF CONSTRUCTION ENGINEERING WITH INTERTEMPORAL CHOICE

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Abstract. The traditional theory of bidder and regulatory agency of construction engineering does not take into account the repeated periodicity of the game between the regulator and regulated party, so that the mathematical point of game equilibrium deviates from actual behavioral expression. According to the intertemporal nature of bidder and regulatory agency, this paper analyzed the payoff matrix of the subject of bidder and regulatory agency, constructed the repeated game behavior model of bidder and regulatory agency, and explored the game conditions of the behavioral expression (steady state and unsteady state) between the two game parties of construction engineering. The results shows that: (1) The administrative triggers are adopted in the normalized regulation, which could make both parties between bidder and regulatory agency reach Pareto Optimality; (2) The intertemporal choice behavior of the bidder is related to the economic punishments, extraneous benefits and legitimate benefits. The increase of economic punishments and legitimate benefits could reduce the illegal behaviors; (3) The larger the discounted function, the easier it is for the bidder to choose long-term legal behavior. Our work indicated that the key to establishing a long-term market mechanism between bidder and regulatory agency is to increase the future impact on the present, and construct the administrative trigger measures of infinitely repeated game.

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1. Introduction

In the bidding process, bidders and government regulatory departments often encounter a game situation: how to choose the game strategy? Whether a large amount of fraud will immediately generate profits, or focus on being honest with each other in order to obtain greater profits in the future? This kind of game needs to weigh the results at different time points, which is called repeated game behavior based on intertemporal choice [1]. The project bidding system is influenced by multiple complex factors, which leads to the frequent

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occurrence of non-healthy repeated game behaviors such as together-conspired bidding, colluding behavior, using deception and so on [2–4]. The repeated game behavior between bidding supervision agencies and bidders aims to maximize the utility of the combination between "current gains/losses" and "future gains/losses" [5–12]. Therefore, the engineering bidding and tendering regulatory behavior is a repeated game behavior problem that faces the intertemporal choice. However, the traditional game model can not explain the frequent illegal behaviors in bidding and tendering. With the continuous evolution of game behavior of bidding and tendering, a large number of regulatory policies also can not completely contain the occurrence of illegal behaviors, so it is in urgent need of new theoretical guidance.

The engineering bidding markets have many fierce competitions. The success of winning the bidding is extremely significant for the survival and development of construction enterprises. In order to win the bidding, the tender even takes risks at any cost and there are more diversified and hidden illegal forms. In order to maintain the fairness and justice of engineering bidding and tendering, regulatory agency often carries out the game behavior to the bidder. The game focus is that the bidder attempts to violate the national and local laws and regulations by unlawful means to obtain excess profits [13–15], while regulatory agency tries to eliminate and punish this illegal behavior to make a profit. The traditional regulatory game is mostly the incomplete information static game [16–19]. If a regulation and inspection process is regarded as a sub-game process, the long-term regulation shall be a repeated game, that is, the regulatory game is a repeated game between regulator and regulatee [20]. The repeated game is a game in which participants repeat the "stage game" with the same structure for many times, and all the participants can observe the history of the repeated game before carrying out the next game. The total benefits of the participants are the simple summation of the game benefits at all stages [21–23]. The Folk Theorem of repeated game [24] believed that if the participants had enough patience, the specific sub-game, perfect Nash Equilibrium of repeated game is the rational feasible benefit vector [25]. Behavioral economics interprets "patience" as the time discount rate of the intertemporal choice, *i.e.* the "benefits/loss" at different time points. The decision makers adopt different time discount rates for discounting and make trade-offs and choices [26, 27]. The time of obtaining benefits obviously affects the selection preference of the gamer – The subjective value of the delayed benefit decreases with the increase of the delay time, that is, the time discounting phenomenon of intertemporal choice. The regulation of engineering bidding and tendering is carried out frequently for a long time, and the repeated game for many times makes the gamer face the intertemporal choice problem-tradeoffs of gain and loss at different stages are carried out in the repeated game of regulation, thus making strategic choices [28–30]. The basic rule of intertemporal choice in the repeated game between bidder and regulatory agency is that the gamer tends to underestimate the forward utility and overestimate the current utility, such as ignoring laws and regulations of engineering bidding and tendering due to current excess earnings, carrying out illegal bidding due to immediate interests while ignoring the engineering quality, carrying out bid ringing, colluding behavior in bidding, collusion and other illegal behaviors due to short-term benefits [31]. The cognitive mechanism of intertemporal choice simplifies psychological motivation to time discount rate [32,33]. The phenomenon of intertemporal choice can be explained by using hyperbolic discounting model to reflect time inconsistency [34,35]. The research results of intertemporal choice can provide enlightenment for improving the rational level of decision makers in bidders and optimizing the regulatory policies of regulatory agency.

The above results can provide a reference for the study of repeated game behavior between bidder and regulatory agency, but the intertemporal nature and time discounting of repeated regulation are not considered, nor is the change of discount rate, which is difficult to explain the abnormal behavior of engineering bidding and tendering market. Based on the intertemporal characteristics of normalization and infinite times between regulator and regulatee, this paper analyzed the repeated game conditions of infinite regulation, constructed the repeated game behavior model between bidder and regulatory agency, assumed the equilibrium conditions that could make the two parties between bidder and regulatory agency achieve the steady state, and revealed the intertemporal behavior decision-making mechanism between bidder and regulatory agency. The research results can provide theoretical basis for the establishment and improvement of engineering bidding and tendering regulatory system. Therefore, this paper fully considered the influence of the intertemporal nature and time discount on the decision-making of both sides of the game.

Based on the intertemporal nature of engineering bidding supervision, this paper analyzed the income matrix of engineering bidding supervision entities, constructed a repeated game behavior model for engineering bidding supervision, and explored the game conditions for the behavior of both parties (steady-state and non-stationary) in the engineering bidding supervision game. The remainder of this article is organized as follows. Section 2 is the description of the problem. Section 3 is the problem analysis. Section 4 is the method analysis. Section 5 is to establish a model and quantify the steady-state equilibrium conditions of the two players. Section 6 is to discuss the results and put forward useful regulatory recommendations. Section 7 summarizes the full text.

2. Utility function of intertemporal choice of repeated game in supervision of project bidding

In the repeated game process between bidder and regulatory agency, the gamer is faced with the intertemporal choice problem-the tradeoffs of immediate and long-term interests. For regular and irregular supervision, the two gamers need to carry out tradeoffs of the gain and loss occurring at different time points and make various judgments and choices. The supervision process of project bidding shows typical intertemporal choice characteristics: Participants may sacrifice immediate interests for the sake of the long-term interests, or may also abandon long-term interests for the sake of the immediate interests. Therefore, in the process between bidder and regulatory agency, the gamer faces the intertemporal choice problem [36], and the repeated game behavior has a typical intertemporal nature.

The repeated game between bidder and regulatory agency has the intertemporal nature, which makes the two parties carry on judgement, comparison and choice for the benefits at different time points, so as to form the discount factor that affects the subjective benefit value of the gamer. From the perspective of behavioral economics, the discount factor represents the patience of decision makers to the future and is an irrational variable [37], which will have an impact on the intertemporal choice and strategic choice of repeated gamer [25, 38]: (1) In measuring the value of future benefits, intertemporal decision makers tend to adopt the higher discount rate for further period, and show the finite rationality and time preference inconsistency of decision makers [33]; (2) The "patience" of bidder determines whether it chooses long-term legitimate earnings while abandoning short-term illegal proceeds. Based on the irrational discounting phenomenon of intertemporal choice, the intertemporal hyperbolic discount rate is introduced:

$$\beta = \frac{1}{1 + \ell d} \tag{1}$$

where β is the discount rate $0 < \beta \leq 1$ between bidder and regulatory agency at t stage and d is the time between bidder and regulatory agency. ℓ represents the parameter of the degree of discount. It is assumed that δ is the tolerance coefficient of time consistency ($0 < \delta < 1$). The interaction time preference at t stage can be represented by the following utility function:

$$U = \delta \bullet u_t + \beta \bullet \sum_{\tau=t+1}^{T} \delta^{\tau} u_{\tau} \tag{2}$$

where u_t is the cardinal instant utility of decision maker at t stage. When $\beta = 1$, it shows that the utility function is exponentially discounted in the time of repeated game; When $0 < \beta < 1$, there is a preference type of "time inconsistency".

3. Anomaly analysis of game behavior between bidder and regulatory agency

For convenience, this paper analyzed the repeated game behavior between bidder and regulatory agency. It is assumed that the game information between bidder and regulatory agency is completely symmetric, bode

TABLE 1. Game matrix between bidder and regulatory agency.

		Bidder	
		Violation p	No violation $(1-p)$
Regulatory agency	Efficient regulation q	$(R-C_1+V,-A)$	$(R-C_1,E)$
	Inefficient regulation $(1-q)$	$(R-C_2-D,E+F)$	$(R-C_2,E)$

parties know the following information: The bidder can obtain illegal benefits through various illegal behaviors. If the regulation of regulatory agency is inefficient, the bidder can "go smoothly"; If the regulatory agency has efficient regulation, the illegal behaviors of bidder will definitely be investigated and the bidder will be punished.

It is assumed that the strategy sets of the regulatory agency and the bidder are $S_1 = \{$Efficient regulation, inefficient regulation$\}$ and $S_2 = \{$violation, no violation$\}$, respectively. The normal utility of the regulatory agency is R (calculated in currency). The cost of efficient regulation by the regulatory agency is C_1 and the cost of inefficient regulation is $C_2 (0 < C_2 < C_1)$. The administrative benefits of the regulatory agency for the successful investigation and punishment of illegal behaviors are V and the administrative loss of the failure to investigate illegal behaviors is D. The lawful proceeds of the bidder are E, and the extraneous earnings of the unlawful transactions of the bidder are F. If the illegal behavior of the bidder is investigated, the economic punishment A shall be imposed and the legitimate benefits can not be obtained. The regulatory game matrix is shown in Table 1.

As shown in Table 1, for the rational gamer with single regulation: (1) When the supervision agency conducts efficient supervision, the best strategy for bidders is not to violate regulations; (2) When the regulatory agency adopts inefficient regulation, the optimal strategy of bidder is to violate the rules; (3) When the bidder chooses not to violate the rules, the optimal strategy of regulatory agency is inefficient regulation; (4) When the bidder chooses to violate the rules, the optimal strategy of regulatory agency depends on the size of $R - C_1 + V$ and $R - C_2 - D$. When $R - C_1 + V < R - C_2 - D$, that is, $C_1 > C_2 + D + V$, the optimal strategy of regulatory agency is inefficient regulation and *vice versa*. It can be seen that $\{$inefficient regulation, violation$\}$ is the only Nash Equilibrium between bidder and regulatory agency game, and is the game theory principle of engineering bidding and tendering game behavior anomalies. It is not difficult to see that the reason for this condition is that the cost of efficient regulation is too high, and the sum of rewards for efficient regulation and penalties for inefficient regulation is less than the cost of efficient regulation, which makes the regulatory agency lack the impetus for efficient regulation. The reasons are that: (1) The experience, technology and means between bidder and regulatory agency are in the stage of continuous exploration and improvement, and the regulation cost of regulatory agency is high; (2) The administrative benefits of regulatory agency by the successful investigation for the illegal behaviors can not significantly improve the efficiency of bidding and tendering market.

For the rational gamer with multiple regulation, when $C_1 < C_2 + D + V$, the repeated regulation game will be caught in an invalid regulatory cycle as shown in Figure 1. At this point, there is no pure strategy Nash Equilibrium in supervision of project bidding game, but only mixed strategy equilibrium. It is assumed that the probability of violating the rules by the bidder is p and the probability of efficient regulation of regulatory agency is q. At this point.

The expected return of efficient regulation of regulatory agency is:

$$p(R - C_1 + V) + (1-p)(R - C_1) = pV + R - C_1. \tag{3}$$

The expected return of inefficient regulation of regulatory agency is:

$$p(R - C_2 - D) + (1-p)(R - C_2) = R - C_2 - pD. \tag{4}$$

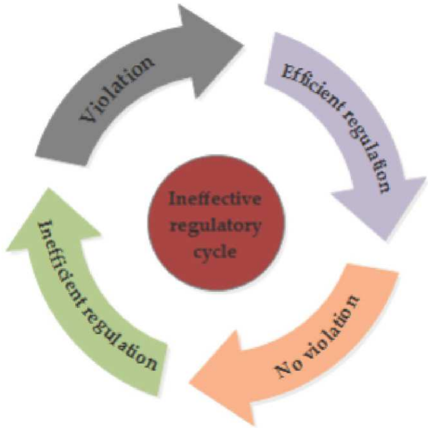


FIGURE 1. Ineffective regulatory cycle: "efficient regulation of regulatory agency → the bidder does not violate the rules → inefficient regulation of regulatory agency → the bidder violates the rules → efficient regulation of regulatory agency…".

The expected return of violating the rules by the bidder is:

$$q(-A) + (1 - q)(E + F) = E + F - q(A + E + F). \tag{5}$$

The expected return of not violating the rules by the bidder is E.

The condition that the regulatory agency chooses the efficient regulation is:

$$pV + R - C_1 > R - C_2 - pD. \tag{6}$$

That is, when $p > (C_1 - C_2)/(V + D)$, the regulatory agency chooses the efficient regulation.

The condition for the legal tendering by the bidder is:

$$E > E + F - q(A + E + F). \tag{7}$$

That is, when $q > F/A + E + F$, the bidder chooses the legal tendering.

To sum up, the mixed strategy Nash Equilibrium of the game is $\{p = (C_1 - C_2)/(V + D),\ q = F/A + E + F\}$, that is, the bidder will choose to violate the rules with the probability of $q = F/A + E + F$. The regulatory agency will choose the efficient regulation with the probability of $p = (C_1 - C_2)/(V + D)$ and can not realize the ideal state of Pareto Optimality.

4. Administrative trigger mechanism of repeated game for infinite regulation between bidder and regulatory agency

The repeated game of finite supervision of project bidding can not realize the ideal Pareto Efficiency improvement [37]. Therefore, when the game termination stage is not set up, the influence of the one-off game equilibrium on the repeated game results at the last stage can be avoided, and the bidder will give up the immediate earnings and choose the long-term benefits, which facilitates both parties between bidder and regulatory agency to adopt the steady-state strategy of {inefficient regulation, no violation}.

The normalized supervision of project bidding makes the participants become ignorant of the last game, which is in line with the characteristics of the infinitely repeated game [21]. The decision-making behavior between bidder and regulatory agency can be analyzed from the angle of infinitely repeated game. At the same time, when setting up a set of administrative trigger measures of bidding and tendering regulation, there is infinitely

Table 2. Game probability matrix between bidder and regulatory agency.

		Bidder	
		Violation	No violation
Regulatory agency	Efficient regulation	$(p_1(D+V)+R-C_1-D,$ $E_2+F-p_1(E_2+F+A))$	$(R-C_1, E_2)$
	Inefficient regulation	$(p_2(D+V)+R-C_2-D,$ $E_1+F-p_2(E_1+F+A))$	$(R-C_2, E_1)$

repeated game between the bidder and regulatory agency: It is assumed that both bidder and regulatory agency adopt the steady-state strategy when supervision of project bidding starts; When it is found that the bidder chooses the unsteady-state strategy, the game steady-state equilibrium of the two parties is broken, and the regulatory agency immediately terminates the steady-state strategy and takes punishment measures, which makes it difficult for the bidder to obtain benefits again. The administrative trigger measures can prevent the the invalid regulation cycle shown in Figure 1.

Under the administrative trigger measures, the repeated game between bidder and regulatory agency occurs continuously. It is assumed that the legitimate benefits of the bidder under efficient regulation are E_2 and the legitimate benefits of the bidder under inefficient regulation are $E_1(E_1 > E_2)$ under the administrative trigger measures. Besides that, it is also assumed that the probability of investigating for the illegal behaviors under efficient regulation is P_1 and the probability of investigating for the illegal behaviors under inefficient regulation E_2 is $p_2(p_1 > p_2)$. At this point, the game matrix of the two parties is shown in Table 2.

If the bidder chooses to violate the rules in t stage and thereafter, the regulatory agency will adopt administrative trigger measures in $t+1$ stage and thereafter and choose the efficient regulation: The earnings in each stage of the bidder before t stage are E_1. The earnings in t stage are $E_1 + F - p_2(E_1 + F + A)$ (recorded as Y) and the earnings after t stage are $E_2 + F - p_1(E_2 + F + A)$ (recorded as X). Among them, $E_2 < X < E_1 < Y$, that is, whether the efficient regulation or inefficient regulation, the legal earnings of the bidder are less than the illegal proceeds $(E < X, E < Y)$, which is also a significant reason for the frequent occurrence of illegal bidding and tendering cases. When $X < E_1$, the illegal benefits of bidder under efficient regulation are less than those under inefficient regulation. On the contrary, if the bidder always chooses to violate the rules, the regulatory behavior of regulatory agency loses its significance.

5. Intertemporal discounting and steady-state condition of repeated game in the supervision of project bidding

5.1. Intertemporal discounted function of repeated game in the supervision of project bidding

The supervision of project bidding game G is given at one stage. $G(\infty, D(K))$ is represented as infinitely repeated game between bidder and regulatory agency, that is, the supervision of project bidding game G will be carried out "infinitely". It is assumed that the time quantum of repeated game between bidder and regulatory agency is $T \in (0, \cdots, t, \cdots, t+k\cdots)$. For the supervision of project bidding game at every t stage, the game result of $t-1$ can be observed before the start of t stage. The earnings of bidder and regulatory agency in $G(\infty, D(K))$ are the sum of discounted value of earnings in the infinite stage game.

To simplify the calculation, it is assumed that the intertemporal discounted function of the bidder and regulatory agency is $D(k)$ $(0 < D(k) < 1)$:

$$D(k) = \frac{1}{1 + \ell t}. \tag{8}$$

The gross proceeds of bidder and regulatory agency are:

$$U^t(c_t, \cdots, c_T) = \sum_{k=0}^{T-t} D(k)^k u(c_{t+k}) \tag{9}$$

where $u(c_{t+k})$ is the cardinal instant utility of both parties in the supervision of project bidding at $t+k$ stage.

5.2. Game steady-state strategy condition of bidder

The condition that the infinitely repeated game between bidder and regulatory agency realizes the steady-state strategy is that: the long-term benefits of bidder and regulatory agency > short-term benefits. This paper discussed the gross proceeds of infinitely repeated game steady-state and unsteady-state strategy in the supervision of project bidding under the administrative trigger measures and quantized the condition between the gamers between bidder and regulatory agency to achieve the steady-state strategy.

When the bidder chooses the steady-state strategy, the present value of gross proceeds is:

$$\begin{aligned} U_1 &= E_1\big(1 + D(k) + D(k)^2 + \cdots + D(k)^{t-2}\big) + E_1 D(k)^{t-1} + E_1\big(D(k)^t + D(k)^{t+1} + \cdots\big) \\ &= E_1 \frac{1 - D(k)^{t-1}}{1 - D(k)} + E_1 D(k)^{t-1} + \frac{E_1 D(k)^t}{1 - D(k)}. \end{aligned} \tag{10}$$

When the bidder does not violate the rules before t stage and chooses to violate rules at t stage, that is, the unsteady-state strategy, the present value of gross proceeds is:

$$\begin{aligned} U_2 &= E_1\big(1 + D(k) + D(k)^2 + \cdots + D(k)^{t-2}\big) + Y D(k)^{t-1} + X\big(D(k)^t + D(k)^{t+1} + \cdots\big) \\ &= E_1 \frac{1 - D(k)^{t-1}}{1 - D(k)} + Y D(k)^{t-1} + X \frac{D(k)^t}{1 - D(k)}. \end{aligned} \tag{11}$$

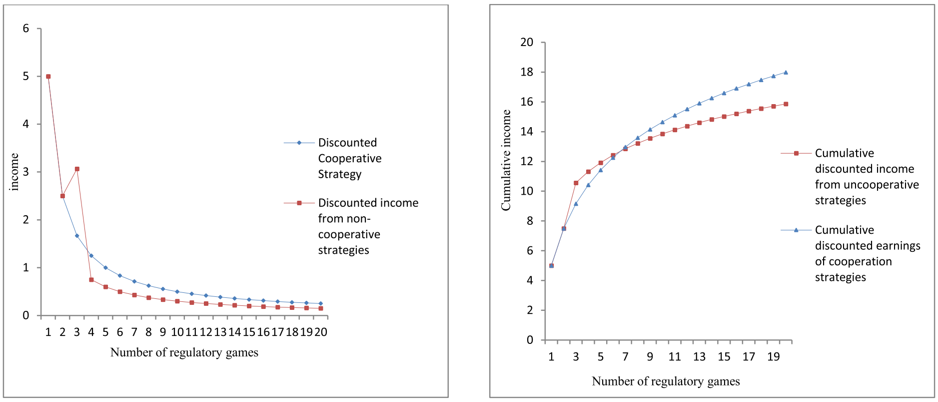
If and only if $U_1 > U_2$, the steady-state condition can be maintained. The steady-state strategy is the perfect equilibrium of sub-game, that is

$$E_1 \frac{1 - D(k)^{t-1}}{1 - D(k)} + E_1 D(k)^{t-1} + \frac{E_1 D(k)^t}{1 - D(k)} > E_1 \times \frac{1 - D(k)^{t-1}}{1 - D(k)} + Y D(k)^{t-1} + \frac{X D(k)^t}{1 - D(k)}. \tag{12}$$

$\frac{Y - E_1}{Y - X} < D(k)$ is obtained. When the discounted function satisfies this formula, no violation is the optimum response of the bidder to the administrative trigger measures by regulatory agency, which constitutes the Nash Equilibrium of infinitely repeated game between bidder and regulatory agency {No violation, inefficient regulation} and is the optimal result of Pareto Efficiency. $D(k)$ is the patient of bidder to the current steady-state strategy in the intertemporal choice stage. The larger the $D(k)$, the closer the intertemporal decision-making behavior of bidder is to the state of Pareto Optimality [37]. At this time, the bidder hopes to continue to adopt steady-state strategy in the future and will comply with the laws and regulations of bidding and tendering market, while regulatory agency does not need to input too much cost in supervision of project bidding, which not only ensures the national social interests and maintains social justice, but also reduces the regulation cost. On the contrary, in the intertemporal choice, the bidder does not try to adopt the long-term steady-state strategy, but only focuses on the immediate short-term benefits. At this point, the bidder has a large probability to carry out illegal behaviors. In order to prevent the illegal behaviors, the regulatory agency is forced to choose the efficient regulation and increase the cost between bidder and regulatory agency. The repeated game equilibrium of regulation can not realize the optimal result of Pareto Efficiency.

X and Y are taken into formula (12), the following formula can be obtained:

$$\frac{F - P_2(E_1 + F + A)}{(p_1 - p_2)(E_1 + F + A)} < D(k). \tag{13}$$



(A) (B)

FIGURE 2. By taking $E_1 = 5$, $\ell = 1$, $Y = 9.2$, $X = 3$ and intertemporal discounted function $D(k) = \frac{1}{1+\ell t}$ and assuming that the bidder chooses the steady-state/unsteady-state strategy at the second stage game, the stage earnings and stage accumulated earnings change graphs of the bidder are drawn (in order to make the image trend easier to observe, the intertemporal discounted function is not processed by exponentiation, and its change trend is not affected), as shown in (A) and (B). It can be seen that under the administrative trigger measures, there is only once that the stage earnings of the unsteady-state strategy is higher than that of the steady-state strategy. With the increase of the number of games in supervision of project bidding, there are more and more accumulated stage earnings of the steady-state strategy. From a long-term perspective, the steady-state strategy under the administrative trigger measures is obviously better than the unsteady-state strategy. However, the intertemporal discounted function gradually decreases with the increase of the number of regulation games, and finally approaches zero infinitely. At this point, regulatory agency should change the regulatory cycle and measures in time to increase the patience of steady-state strategy of bidder. (A) Stage income change of repeated game of bidder under administrative trigger measures. (B) Stage accumulated income change of repeated game of bidder under administrative trigger measures.

At this time, there may be two conditions: (1) If the extraneous earnings F is less than $P_2(E_1 + F + A)$, the value of $\frac{F-P_2(E_1+F+A)}{(p_1-p_2)(E_1+F+A)}$ is negative, which indicates that if only $D(k) > 0$, the present value brought by the steady-state strategy of the bidder is greater than by the unsteady-state strategy. (2) If the extraneous earnings F is larger than $P_2(E_1 + F + A)$, the range of intertemporal discounted function by the bidder to choose the steady-state strategy is $\frac{F-P_2(E_1+F+A)}{(p_1-p_2)(E_1+F+A)} < D(k) < 1$ (Fig. 2).

5.3. Game steady-state strategy condition between bidder and regulatory agency

If the bidder or the regulatory agency first breaks the situation of {inefficient regulation, no violation} and chooses the efficient regulation at t stage and thereafter, under this condition, the bidder must choose the illegal behavior at $t + 1$ stage and thereafter. The total present value of income of the regulatory agency is:

$$
\begin{aligned}
U_3 &= (R - C_2)\big(1 + D(k) + \cdots + D(k)^{t-2}\big) + (R - C_1)D(k)^{t-1} \\
&\quad + (p_1(D + V) + R - C_1 - D)\big(D(k)^t + D(k)^{t+1} + \cdots\big) \\
&= (R - C_2)\frac{1 - D(k)^{t-1}}{1 - D(k)} + (R - C_1)D(k)^{t-1}
\end{aligned}
$$

$$+ (p_1(D+V) + R - C_1 - D)\frac{D(k)^t}{1-D(k)}\cdot \tag{14}$$

The total present value of income of the regulatory agency with inefficient regulation is:

$$\begin{aligned} U_4 &= (R - C_2)\big(1 + D(k) + \cdots + D(k)^{t-2}\big) \\ &\quad + (R - C_2)D(k)^{t-1} + (R - C_2)\big(D(k)^t + D(k)^{t+1} + \cdots\big) \\ &= (R - C_2)\frac{1 - D(k)^{t-1}}{1 - D(k)} + (R - C_2)D(k)^{t-1} + (R - C_2)\frac{D(k)^t}{1 - D(k)}\cdot \end{aligned} \tag{15}$$

Comparing the two conditions, when $U_4 > U_3$, the regulatory agency will always choose inefficient regulation, and the bidder will not be forced to choose illegal behavior. At this point, there are three circumstances: (1) When $p_1(D+V) = D$, that is, $p_1V = (1-p_1)D$, the administrative expected income of the regulatory agency with efficient regulation is equal to the administrative expected punishment. Whether the bidder chooses any strategy, the benefits of the regulatory agency are $(R - C_1)$. The regulatory agency lacks of regulation motivation; (2) When $p_1(D+V) > D$, that is, $\frac{(C_1-C_2)}{p_1(D+V)-D} > D(k) > 0$, if the bidder maintains the law-abiding behavior, the regulatory agency will always choose inefficient regulation; If the bidder breaks the rules once, the regulatory agency will choose efficient regulation in the next stage game. At this point, $p_1(D+V) + R - C_1 - D$ is greater than $R - C_1$. The regulatory agency has a higher regulation efficiency; When $p_1(D+V) < D$, $\frac{(C_1-C_2)}{p_1(D+V)-D} < D(k)$ and $\frac{(C_1-C_2)}{p_1(D+V)-D}$ is negative, which indicates that if only $D(k) > 0$, the regulatory agency will always choose inefficient regulation (Fig. 3).

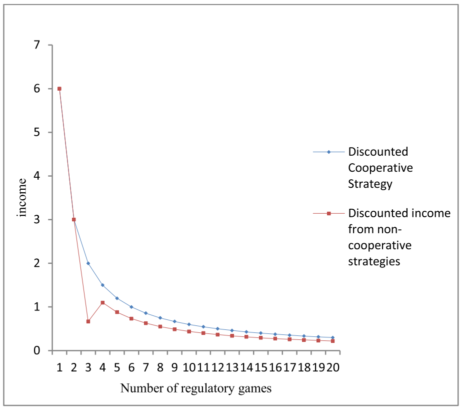
6. Discussion and suggestion

6.1. Result discussion

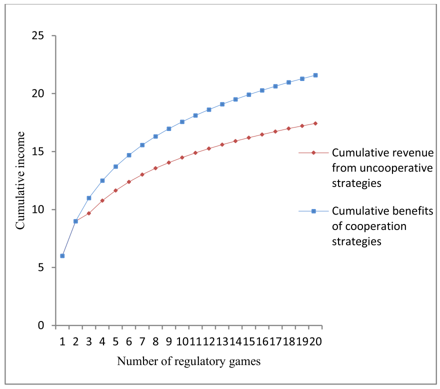
Under the premise of protecting the public interests, the equilibrium point between bidder and regulatory agency is to realize the benefit maximization for both parties. The decision-making behavior of the repeated gamer between bidder and regulatory agency is influenced by the intertemporal discount rate, but the traditional regulatory game does not consider the intertemporal nature of the multiple regulation, nor does it consider the problem of the discount rate change. Therefore, introducing the intertemporal discounted function to establish the game behavior model and solving the equilibrium condition of the steady-state infinitely repeated game have high ecological game behavior validity. From the perspective of intertemporal choice, it can be seen by analyzing the repeated game behavior model between bidder and regulatory agency and its equilibrium solution that:

(1) The finite repeated game between bidder and regulatory agency can not reach the ideal Pareto Optimality. In the process of infinitely repeated game between bidder and regulatory agency, the steady-state termination mechanism-administrative trigger measures are set up, and the intertemporal discounted function $D(k)$ is introduced to quantize the game steady-state equilibrium condition. The bidder will abandon the pursuit of the short-term smaller interests under the real pressure of the administrative trigger measures by the regulatory agency, and obtain the long-term greater benefits in turn by observing the national laws and regulations and conscientiously fulfilling the bidding and tendering contract.

(2) The probability of the bidder choosing the law-abiding behavior related to economic punishment, extraneous income and legal earnings. On the one hand, the regulatory agency should formulate corresponding measures to increase the legal benefits of the bidder and increase the economic punishment intensity for the illegal behaviors of bidder. On the other hand, for the extraneous income, the regulatory agency should strengthen the regulatory measures, increase the visualization and transparency of bidding and tendering transactions, and reduce the generation of extraneous income.



(A)



(B)

FIGURE 3. By taking $R - C_2 = 6$, $\ell = 1$, $R - C_1 = 2$, $p_1(D + V) + R - C_1 - D = 4.4$ and intertemporal discounted function $D(k) = \frac{1}{1+\ell t}$, if the regulatory agency first breaks the steady-state condition, the repeated game stage income and accumulated stage income change graphs of the regulatory agency are drawn under the steady-state/unsteady-state condition (in order to make the image trend easier to observe, the intertemporal discounted function is not processed by exponentiation, and its change trend is not affected), as shown in (A) and (B). Different from the stage income increase of bidder by first breaking the steady-state condition, the unsteady-state strategy of the regulatory agency directly leads to its income decrease. Therefore, when the bidder maintains the steady-state strategy, the regulatory agency will not easily choose the unsteady-state strategy. (A) Repeated game stage present value of earnings change of the regulatory agency. (B) Repeated game accumulated stage present value of earnings change of the regulatory agency.

(3) The more long-term interests the bidder pays attention to, the easier it is for the bidding and tendering organization and bidder to achieve the game steady-state condition. Whether the bidder pays attention to the long-term benefits is related to the intertemporal discounted function $D(k)$. The larger the $D(k)$ is, the more important the future is than the present, and the easier it is to reach the steady-state condition; On the contrary, if $D(k)$ is not large enough, there is no game form that can reach the steady-state condition. When the numerical value of $D(k)$ is large enough, it means that the time value of money is higher. The longer the bidder chooses the steady-state strategy, the more profits it will obtain, which is far more than the extraneous income brought by illegal behaviors. The bidder has a high degree of pursuit of long-term benefits and the probability of illegal behavior is small.

(4) According to the range of intertemporal discounted function of steady-state strategy by the bidder, it can be seen that the probability of bidder violating laws and rules is related to the probability of successful investigation by the regulatory agency. The higher the probability of successful investigation by the regulatory agency, the lower the probability of bidder violating the laws and rules and *vice versa*. Thus it can be seen that improving the professional proficiency of the regulatory agency can reduce illegal behaviors to a certain extent. The minor punishment intensity to the illegal behaviors stimulates the bidder to pursue illegal earnings, thus generating more illegal behaviors. In the case of ensuring the regulation intensity, the regulatory agency should formulate measures to reduce the regulation cost and increase the reward for successful investigation and punishment for failure. Increasing the training of the personnel of the regulatory agency and improving their professional and technical level and work efficiency can not only save the regulation cost, but also reduce the illegal behavior of the bidder.

6.2. Policy suggestion

The bidder and regulatory agency are the decision-making subjects of the repeated game between bidder and regulatory agency, and are the decisive factor that determines whether the game can achieve the steady-state condition [39]. Therefore, combining with the above analysis results, in the game decision-making stage, this paper fully considered the intertemporal characteristics of regulatory repeated game and put forward some suggestions to reduce the illegal behavior of bidder:

(1) The reward and punishment system for illegal acts by bidding regulatory agencies is aimed at maintaining a fair, transparent, and honest bidding market order, ensuring the efficiency of resource allocation, and maximizing public interests.

   (1) Reward system.
   Reward for good credit enterprises: priority consideration, bonus points, or additional rewards will be given to enterprises with no illegal behavior and good credit records.
   Actively participating in training rewards: provide certain rewards to enterprises that participate in training on bidding laws and regulations, integrity management, etc.
   Innovation technology rewards: encourage and reward enterprises with innovative technologies or contributions, such as providing additional evaluation scores or prioritizing project acceptance.

   (2) Punishment system.
   Penalty amount: for discovered illegal behaviors, fines shall be imposed in accordance with the nature and circumstances of the illegal behavior in accordance with the law and regulations. The amount of fines may be calculated based on the illegal income or relevant standards.
   Punishment filing: for enterprises that engage in serious illegal activities, punishment filing shall be carried out to limit their participation in bidding activities, or their qualification for bidding shall be permanently cancelled.
   Blacklist system: establish a blacklist of illegal and irregular activities, publicize enterprises with serious illegal behaviors, and increase regulatory efforts to restrict their participation in bidding activities for a certain period of time.
   Cancellation of contract qualification: for enterprises that have committed serious illegal acts, their contract qualifications that have already won the bid can be revoked in accordance with laws and regulations, requiring a new bidding process or being undertaken by the second highest scoring enterprise.

   It should be noted that the specific reward and punishment system should be formulated in accordance with local laws and regulations and the actual situation, ensuring fairness, fairness, rationality, and enforceability. At the same time, regulatory agencies should strengthen monitoring and inspection of illegal activities, strengthen the construction of industry integrity systems, increase the cost of illegal activities, and effectively curb the occurrence of illegal activities.

(2) In bidding, intertemporal choice is an important strategy that can help bidders better grasp the initiative. The following are the systems or suggestions that can be considered:

   (1) Introducing a multiple quotation system: allowing bidders to quote multiple times at different time periods, which can more effectively reflect market changes and competition. This system will increase the flexibility of bidding and provide bidders with the opportunity to optimize their quotations by observing market dynamics.

   (2) Establishing an electronic bidding system: using an electronic bidding system can effectively reduce the participation cost of bidders, while also facilitating the collection and comparison of bidding proposals by the bidding party. Cross period selection can also be well reflected in the electronic bidding system, where bidders can update their quotes or choose to exit at any time.

   (3) Introducing cooperation mechanisms: introducing cooperation mechanisms during the bidding process can enable bidders to share information and resources through alliances or partnerships, in order to gain greater competitive advantages. In cross period selection, cooperation mechanisms can also provide bidders with more time and resources to observe and analyze market dynamics, in order to better grasp the timing.

(4) Standardize bidding behavior: to ensure fairness and effectiveness in cross period selection, it is necessary to standardize bidding behavior. For example, conducting pre qualification for bidders, establishing strict confidentiality measures, and specifying bidding schedules and procedures.
(5) Provide opportunities for information disclosure: provide both bidders and bidders with the opportunity to obtain sufficient information to make informed decisions. This can be achieved through organizing information conferences, providing consultation or Q&A services, and other means.
(6) Establish a supervision mechanism: to prevent potential fraudulent behavior during the bidding process, a supervision mechanism should be established to ensure fairness, impartiality, and transparency in the bidding process. Supervision mechanisms can include supervisors, auditors, or third-party institutions.

In short, intertemporal choice has important application value in bidding game behavior. By introducing multiple quotation systems, establishing electronic bidding systems, introducing cooperation mechanisms, standardizing bidding behavior, providing information disclosure opportunities, and establishing supervision mechanisms, measures can effectively promote healthy competition in bidding, improve resource allocation efficiency, and economic and social development benefits.

7. Conclusion

The regulatory behavior of engineering bidding and tendering is a repeated game behavior problem that faces the intertemporal choice. Based on the traditional regulatory game model, this paper established the game income matrix of both bidder and regulatory agency, determined the intertemporal utility function combined with the intertemporal nature, and constructed the repeated game behavior model between bidder and regulatory agency. The conclusions are as follows:

(1) This paper analyzed the reasons for frequent violations of laws and regulations in engineering bidding transactions: high regulatory costs and low efficiency. An administrative trigger mechanism based on bidding supervision agencies was proposed to quantify the game conditions for the behavior of both parties in the engineering bidding supervision game, determined the relationship between the intertemporal discount function and the bidder's intertemporal decision-making behavior, and studied the impacts of additional benefits, legal benefits and economic penalties on the cross period discount function.
(2) Based on the intertemporal choice psychological mechanism and repeated game behavior analysis between bidder and regulatory agency, for the sake of improving the long-term mechanism, this paper gave the following suggestions: (1) the regulatory agency should increase the economic punishment intensity and amount for the illegal behaviors of bidder; (2) the main emphasis must be on the need to increase impact of the future on the present in administrative system; (3) administrative departments should build a future-oriented bidding supervision mechanism.

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Conflict of Interest

The authors declare no conflict of interest.

Author contribution statement

Conceptualization, Wenjie Yao; methodology, Qian Zhang; software, Qian Zhang; validation, Guilian Jiang and Ying Chen; formal analysis, Qian Zhang; investigation, Guilian Jiang; writing – original draft preparation, Wenjie Yao, Guilian Jiang, Ying Chen, and Qian Zhang. All authors have read and agreed to the published version of the manuscript.

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