Stability Analysis of Cooperation between Owners and Contractors in the Construction Market

Zhongfu Qin*, Fang Hua and Hua Tang

1 Associate Professor, Institute of Civil Engineering Management, Zhejiang University, China
2 Graduate Student, Institute of Civil Engineering Management, Zhejiang University, China
3 Engineer, Hangzhou Development Planning & Research Institute, China

Abstract
In a price-driven, low-bid system a cooperative contract may be helpful in reducing problems that arise from competitive bidding. In this article, the authors examine the stability of cooperation between owners and contractors through a repeated game model with provident partners. Firstly, the profits of defecting and cooperating partners are compared to determine whether there is motivation to defect. This comparison is achieved by using a dynamic model to calculate the loss and recovery of trust. Secondly, the authors examine the relationship between stability and its influential factors under the condition of partner changing. The authors' examination reveals that stability of cooperation correlates negatively with both the recovery velocity of trust and the probability of undiscovered defection, but has a positive correlation with the number of consecutive defections. Furthermore, the possibility of extra profit is the key motivation for unilateral defections under the condition of fixed partners. The authors conclude by proposing methods for maintaining the stability of cooperation.

Keywords: cooperation; defection; stability; repeated game; trust recovery

1. Introduction
In China's current construction market, contractor selection is usually price-oriented. The lowest tender price is typically awarded the contract, and the contractor's ability to control the project schedule and quality is generally not taken into account (Wu and Lo, 2009). In order to be successful in the bidding, some contractors may reduce their quote by reducing the quality of work, and obtain Beyond-Contractual Rewards (BCR) by "cutting corners" and making financial claims after initiating construction, both of which could negatively impact the quality of public projects (Lo et al. 2007). Therefore, the shortcoming of a low-bid system is that it relies too heavily on price to evaluate contractors' competitiveness.

Waara and Brochner (2006) have stated that owners should, when awarding contracts, apply non-price criteria, such as quality provisions, technical solutions, and environmental policy and service, as a supplement of the price criteria. However, neither of the above authors investigated trust dynamically with a mathematical model. The analysis

*Contact Author: Zhongfu Qin, Associate Professor, Institute of Civil Engineering Management, Zhejiang University, Hangzhou, 310058 China
Tel: +86-135-8888-1729 Fax: +86-571-8820-8685
E-mail: qinzhongfu@zju.edu.cn
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in this paper is from the latter viewpoint concerning trust, and sections in this paper will describe the loss and recovery of trust due to defection and consecutive cooperation.

Stability is a vital evaluation criterion of cooperative efficacy. Currently, the major analysis tool of cooperative stability is Game Theory (GT) (Bendor and Swistak, 1997), which is effective for analyzing decision makers’ rational behavior when they have different goals, the action of which can influence one another (Per Erik, 2007). Nagarajan and Sosic (2008) built a negotiation model describing stability mathematically, but they did not offer a solution to their model, and could not explain quantitative relationships between cooperative stability and its influencing factors. Studies (Sherratt and Roberts, 2002, Per Erik, 2007) using Prisoner’s Dilemma have been based on data, but the mathematical deduction were lacking. Conlon (2003) included the Repeated Game model in his quantitative analysis, but with the assumption of players’ shortsightedness. To achieve a more effective and applicable solution, the authors have replaced the actual data in previous studies with parameters and have analyzed the relationship between cooperation stability and its influential factors through a repeated game model with farseeing participants.

2. Model

In essence, the stability between owners and contractors is a 2x2 game. In the 2x2 game, it is assumed that each player has two strategies: cooperate and defect. Owners choosing cooperation signifies that they will offer contractors favorable terms based on trust, such as reducing the supervision, considering and accepting the changes suggested by contractors, accepting contractors’ reasonable claims in a timely manner, and so forth. While, if owners choose to defect, there would be no favorable terms, and owners might delay payment and refuse claims to temporarily reduce costs. Similarly, contractors choosing to cooperate signifies that they will complete the project on schedule with high quality and lowest cost, while defection may cause unreasonable claims, construction delay, and even the "cutting of corners" to obtain BCR (Lo et al., 2007). Both players could choose one of the two strategies independently, resulting in one of four pay-off outcomes, denoted (owners' strategy, contractors' strategy), in Fig.2.1.

| Contractors | Cooperate(C) | Defect(D) |
|-------------|--------------|-----------|
| Owners      |              |           |
| Cooperate(C)| $b_1, b_2$   | $d_1, c_2$|
| Defect (D)  | $c_1, d_2$   | $a_1, a_2$|

Fig.2.1. Pay-offs for Owners and Contractors

The figure shows that a party could obtain $a$ or $b$, respectively, when both are defecting $(D, D)$ or both are cooperating $(C, C)$. The symbol $c$ is the temptation of one player to defect, and $d$ is the other player's pay-off. Subscripts 1 and 2 in Figure 2.1 respectively mark pay-offs for owners and contractors. Generally, players benefit more from mutual cooperation than mutual defection (Erik W. Larson, 1994), and when one chooses to defect while the other continues cooperating, the defector will receive ill-gotten gains and the cooperator will suffer losses. Thus, there are the following relationships of most to least desirable scenarios: $c > b > a > d$ and $b + b > c + d$. These scenarios reflect the Prisoner’s Dilemma (Per Erik, 2007). Per Erik (2007) concluded that there were five factors influencing cooperation in the Prisoner’s Dilemma:

1. The length of the game. The length adopted in this paper is infinite, which means that owners and contractors intend to participate in the construction market, without quitting after a finite number of projects. This requires players to be far-sighted in the model, considering profit in the future rather than immediate or short-term advantages.

2. The size of the pay-offs. The pay-offs in a single game are expressed by parameters instead of specific values in this paper. The impact of the size of pay-offs on cooperation stability will be analyzed in section 3.2.

3. The discount parameter. This parameter reflects the effect of future profit to current decision-making. This paper assumes that every cooperation period is of the same length, and uses the discount parameter $\delta$, relevant to interest rate $r$.

4. The players’ strategies. It is presumed in this paper that every player in the model refuses to cooperate with a known defector. In other words, a player will only cooperate with a partner who lacks a history of defection.

5. The amount of trust between players. The authors will build a dynamic mathematical model to describe the change in the amount, loss, and recovery of trust in section 3.1.

3. Repeated Game Analysis

As mentioned in section 2, players will participate in the market for an infinite time period, and they will make decisions taking into consideration the long-term profit. Therefore, the Repeated Game model is adopted, for games between owners and contractors are repeated time and time again.

Let $\pi_t$ be the pay-off for each player in the present value of total repeated games, such that:

$$\pi_t = \pi_1 + \delta \pi_1 + \delta^2 \pi_1 + \cdots = \sum_{t=1}^{\infty} \delta^{t-1} \pi_t$$

(3.1)

where $\pi_t$ is the pay-off of equilibrium in a single game, namely period $t$, $\delta = 1/(1+r)$ is the discount parameter, $r$ is the interest rate for the interval between adjacent periods, and where $r \geq 0$ and $0 < \delta \leq 1$.

When outcome $(C, C)$ happens in every period, there is $\pi_t = b$, and then:

$$\pi_t = b$$

(3.2)
The present revenue for each player is:

$$\pi = b + b \times \delta + b \times \delta^2 + \ldots = \frac{b}{1 - \delta} \quad (3.2)$$

If one player values the immediate, rather than the long-term, benefit and chooses to defect unilaterally, the other player will, after realizing the defection has occurred, clear the trust on the defector and choose to play strategy D in all of the future games with the defector. In this scenario, the foremost of the defector has only two options: turning to a new partner or staying with the initial partner, which will be discussed in section 3.1 and 3.2, respectively.

### 3.1 Analysis with partner change

After a defection, the defector could select another partner in the construction market to replace the initial partner, and choose to cooperate or defect the new partner as well.

If the player insists on defecting in sequential games, it is possible to gain more profit than cooperation, considering that the information of the market may not, at least in the short term, be transparent enough to prevent this. As the defections continue, however, the probability that other partners will discover the behavior increases. As mentioned in section 2, other partners in the market would not cooperate with this known defector.

Let $\varepsilon$ be the probability that defector's behavior is undiscovered in a single game, then after $n$ sequential defections, the probability of undiscovered defection is $\varepsilon^n$, assuming that the discovery of defection in a given period is an independent event. Thus, the probability that the next partner cooperates with the defector is $\alpha(1-\varepsilon)$ as well. In this case, the expected revenue of a defector's $n$th sequential defection is:

$$c \times \varepsilon^{n-1} + \alpha \times (1 - \varepsilon^{n-1}) = \alpha + (c - a) \varepsilon^{n-1} \quad (3.4)$$

where $0 \leq \varepsilon \leq 1$. It can be seen from (3.4) that as the number of defections increases, the expected revenue of single defection decreases to $a$. However, if there is no defection, each player could receive a pay-off of $b$, and $a < b$. Hence, a defector may return to cooperation with the precondition of existing in the market indefinitely, in the hope of increasing long-term profit. However, even when the previously defecting partner portrays its sincerity concerning cooperation, a new partner may still believe defection will occur again, given the previous history. Thus, it is not clear which strategy the next partner will take, though every new partner will take C or D largely according to information about the defector.

For example, a partner $A$ has defected in the last $N-1$ periods. At period $N$, $A$ decides to be a partner with integrity, and chooses to cooperate with the new partner. The amount of the partner's trust of $A$ is $\varepsilon^N$ in this period, equal to the probability of the $N-1$ defections undiscovered. The amount of trust here is not the probability of whether the new partner trusts $A$ in the condition that it has seen $A$ clearly, but the probability of whether it trusts $A$ according to its knowledge about the credit history of $A$. Hence, the expected revenue for $A$ in period $N$ is:

$$b \times \varepsilon^{N-1} + d \times (1 - \varepsilon^{N-1}) = d + (b - d) \varepsilon^{N-1} \quad (3.5)$$

It can be seen from (3.5) that the expected revenue decreases to $d$, as the number of defections $N$ increases. The reason for this is that the defector's treachery has shattered the trust of other partners. It is assumed that the lost trust could be recovered by the effort of sequential cooperation with sincerity, no matter whether the partner chooses C or D, and this assumption is in accord with reality.

Another assumption is that the length of trust recovery is in direct proportion to the previous defection numbers, i.e., if $A$ has defected $N$ times, it will take $\mu N$ sequential C events to make other partners trust $A$ as if it was an ordinary player without a defection history. Taking $\nu = \mu$ as the Recovery Velocity of Trust, $\nu \neq 0$, the authors obtain:

$$X = \begin{cases} \varepsilon^{N-t}, & t \leq \mu N \\ 1, & t > \mu N \end{cases} \quad (3.6)$$

where $X$ is the amount of trust from the partner, $N$ is the number of previous defections, and $t$ is the number of cooperations since the last defection ($0 < X \leq 1$, $N = 1, 2, 3, \ldots$, and $t = 1, 2, 3, \ldots$). The probability that the new partner cooperates with $A$ is $X$, and the defection probability of the partner is $1-X$. Then the expected revenue for $A$ in the $t$th cooperation after $N$ defections is:

$$b \times X + d \times (1 - X) = b \times \varepsilon^{N-t} + d \times (1 - \varepsilon^{N-t}) = b \times (b - d) \varepsilon^{N-t} \quad (3.7)$$

where $t \leq (\mu N + 1)$. Equation (3.7) shows that the expected revenue is $b$, when $t = (\mu N + 1)$, which means that in the $(\mu N + 1)$ th game since the last defection, $A$ could be treated as a player having no defection history, and the probability that $A$ is trusted by the partner is 1. The process length of trust depletion and recovery is $(1 + \mu)N$, and the earning of $A$ is as it would have been before any defections. The total pay-off for $A$ during the $(1 + \mu)N$ games is:

$$\pi = \sum_{j=1}^{\mu N} [a + (c - a) \varepsilon^{j-1}] + \sum_{j=1}^{\mu N} [b + (b - d) \varepsilon^{N-j+1}]$$

$$= (a + d) \frac{N}{\nu} + (c - a) \frac{1 - \varepsilon^N}{1 - \varepsilon} + (b - d) \frac{\varepsilon^N (1 - \varepsilon^N)}{1 - \varepsilon} \quad (3.8)$$
For the purpose of simplifying calculations, consider $\delta=1$, which signifies that future pay-offs are worth as much as the current pay-off (Per Erik, 2007). The average pay-off for $A$ during the $(1+\mu)N$ games is:

$$
\pi_A' = \frac{a+d/v + (c-a)\frac{1-\varepsilon^N}{1-\varepsilon} + (b-d)\frac{\varepsilon'(1-\varepsilon^N)}{(1+1/v)N}}{1+1/v}.
$$

(3.9)

It can be seen from (3.9) that $\pi_A'$ (the average pay-off during periods of trust lost and recovered) is related to $\nu$ (the recovery velocity of trust), $\varepsilon$ (the probability of undiscovered defection), and $N$ (the number of defections).

3.1.1 Relation between $\pi_A'$ and $\nu$

The partial derivative of $\pi_A'$ to $\nu$ is obtained as follows:

$$
\frac{\partial \pi_A'}{\partial \nu} = \left(\frac{b-d}{1+1/v}\right)\frac{\ln \varepsilon \cdot \varepsilon' \left(1-\varepsilon^N\right)}{(1+1/v)(1-\varepsilon)^2 N} + \frac{a-d}{(1+1/v)^2} \frac{1-\varepsilon^N}{1-\varepsilon} + \frac{(c-a)\frac{1-\varepsilon^N}{1-\varepsilon} + (b-d)\frac{\varepsilon'(1-\varepsilon^N)}{(1+1/v)N}}{1+1/v}.
$$

(3.10)

It can be seen in (3.10) that when $N$ is large enough, the value of $\frac{\partial \pi_A'}{\partial \nu}$ approaches $\frac{a-d}{(1+1/v)^2} > 0$.

Under the condition that $A$ has defected a sufficient number of times and the values of $\varepsilon$ and $N$ are fixed, increases in $\nu$ lead to increases in $\pi_A'$. In other words, the more quickly the defector recovers its credit, the more profit it can obtain between the period of trust lost and trust recovered, and vice versa. If both owners and contractors in the market were to give more weight to credit history when choosing a potential partner, for a defector, it would be difficult to recover the trust from others in a short period of time, and the average pay-off due to defections would be reduced. This, in turn, would decrease the motivation for defections and increase the stability of cooperation.

3.1.2 Relation between $\pi_A'$ and $\varepsilon$

Equation (3.11) calculates the partial derivative of $\pi_A'$ to $\varepsilon$:

$$
\frac{\partial \pi_A'}{\partial \varepsilon} = \left(\frac{b-d}{1+1/v}\right)\frac{\ln \varepsilon \cdot \varepsilon' \left(1-\varepsilon^N\right)}{(1+1/v)(1-\varepsilon)^2 N} + \frac{a-d}{(1+1/v)^2} \frac{1-\varepsilon^N}{1-\varepsilon} + \frac{(c-a)\frac{1-\varepsilon^N}{1-\varepsilon} + (b-d)\frac{\varepsilon'(1-\varepsilon^N)}{N(1+1/v)(1-\varepsilon)}}{1+1/v} > 0.
$$

(3.11)

where $1+(N-1)\varepsilon^N - N\varepsilon^{N-1} > 0$ can be proved. Equation (3.11) indicates that increases in $\varepsilon$ result in increases in $\pi_A'$ with constant values for $\nu$ and $N$. This means that profit for the defector during periods of trust lost and recovered increases as the probability of undiscovered defection increases. Therefore, the transparency of information between partners is negatively correlated to the occurrence of defection. A stricter supervision system and sufficient information sharing may reduce the probability of defection and increase the stability of cooperation.

3.1.3 Relation between $\pi_A'$ and $N$

Let $f(N) = \pi'[1+(1+\mu)N]/(1+\mu)N$ and calculate the partial derivative of $\pi_A'$ to $N$:

$$
\frac{\partial f(N)}{\partial N} = \frac{\partial \pi_A' \partial f}{\partial N} = \frac{(c-a)\frac{1-\varepsilon^N}{1-\varepsilon} + (b-d)\varepsilon' \left(1-\varepsilon^N\right)}{N^2(1+1/v)(1-\varepsilon)} < 0,
$$

(3.12)

where $\varepsilon^N - N(1/n)\varepsilon^N - 1$ can be proved as well. Equation (3.12) indicates that $\pi_A'$ decreases as the number of defections increases with constant values of $\nu$ and $\varepsilon$.

For the purpose of maximizing profits, players will perform defections under the condition that they could earn more, i.e., $\pi_A' \geq \pi_A$. As $f(N)$ is a monotonic decreasing function of $N$, when $f(N) \geq \pi_A$ and $f(N+1) < \pi_A$, $N$ is the optimal number of defections, and the highest profit is gained by performing $N$ defections.

Similarly, because $f(N)$ is a monotonic decreasing function of $N$, players would have no reason to defect if market information was transparent enough, and the defector could get no more profit than cooperation. When $N=1$, which signifies that a defection only happens in the first period, the average revenue during the period of trust lost and recovered is:

$$
\pi_A'_{\max} = \frac{a+d/v + (c-a)\varepsilon'(1-\varepsilon^N) + (b-d)\frac{1-\varepsilon^N}{(1+1/v)N}}{1+1/v}.
$$

(3.13)

It is required that $\pi_A'_{\max} < \pi_A = b$ to prevent defections from happening, so one can calculate that:

$$
\frac{a+d/v + (c-a)\varepsilon'(1-\varepsilon^N) + (b-d)\frac{1-\varepsilon^N}{(1+1/v)N}}{1+1/v} < b
$$

(3.14)

One can then obtain:

$$
\varepsilon' \left(1-\varepsilon^N\right) > \frac{1-c/b}{b-d} < 1
$$

(3.15)

Equation (3.15) requires $b=b_0>(c+b+d)/(\nu+1)$, which means that only when the pay-off of mutual cooperation in a single game is large enough is there the possibility of putting an end to defections. Specifically, when $\nu=1$, i.e., when trust could be recovered by a single cooperation after a defection, $2b>\varepsilon+b$ should be satisfied to stop defections. Further, $\partial b_0/\partial \nu = (c-d)/(\nu+1)^2 > 0$ indicates that the more quickly trust is recovered, the greater the required pay-off of mutual cooperation to prevent players from defecting, a conclusion consistent with real-world business.
On the basis of the above, it can also be proved that 
\( \epsilon'/(1-\epsilon)/(1-\epsilon') \) is a monotonic increasing function of \( \epsilon \), if there is an \( \epsilon_0 \) satisfying:

\[
\frac{\epsilon_0' (1 - \epsilon_0)}{1 - \epsilon_0} = \frac{1}{\nu} \frac{c - b}{b - d} \tag{3.16}
\]

Then \( \epsilon_0 \) can be recognized as a critical probability of defections undiscovered, which ensures that defectors will never achieve extra profit other than by cooperation. When there is \( \epsilon \leq \epsilon_0 \), i.e., when market information is sufficiently transparent, no matter how many defections are performed, the average revenue during periods of trust lost and recovered will be no more than the profit of mutual cooperation for any player, and the cooperation will remain highly stable.

3.2 Analysis with partner fixity

When owners and contractors intend to establish cooperation, transaction costs will be higher as a result of costs associated with evaluating the potential partner and preparing for the implementation of cooperation. However, if cooperation continues for long enough, the average transaction costs for both players will be less than that of bidding (Waara and Brochner, 2006, Eriksson, 2008), which is a reason why players should prefer cooperation. Moreover, players should want to obtain further profit by strengthening the cooperation relationship. Therefore, it is expected that, more often than not, one partner tends to cooperate with a fixed partner.

If there is no partner changing after a defection, the probability of defection being undiscovered will be 0. According to the trust model in section 3.1, the amount of trust from the partner is 0, and the lost trust cannot be recovered because the partner is fixed. Then the outcome of (D, D) will occur in all of subsequent games, with the pay-off of \( a \). Under this circumstance, neither of the players will choose the strategy of C, resulting in a pay-off of \( d \), which is obviously unfavorable.

If a defection happens in the first period, the defector will receive a pay-off of \( c \) immediately, and (D, D) will be the outcome of subsequent games. The present value for the defector with a discount parameter of \( \delta \) is:

\[
\pi'_v = c + a * \delta + a * \delta^2 + \cdots + c + \frac{a \delta}{1 - \delta} \tag{3.17}
\]

Similarly, if the first defection occurs in the period \( t \), \( t \geq 2 \), the average revenue for the defector of total games will be:

\[
\pi'_v = (1 - \delta)^t \sum_{i=0}^{t} \delta^{t-i} \pi_t = b + \delta^t [c - b - (c - a) \delta] \tag{3.18}
\]

To stop defections in the market, there should be \( \pi'_v \leq \pi_t \) and \( \pi''_v \leq \pi_t = b \), and one obtains:

\[
\delta = \frac{1}{(1+r)} > \frac{(c-b)}{(c-a)} \tag{3.19}
\]

Equation (3.19) shows that the lower the value of \( (c-b)/(c-a) \), or the higher \( \delta = 1/(1+r) \), the more cooperation is stable. In other words, if the pay-off of cooperation is sufficiently more than that of defection, or if partners place more weight on future profit, the stability of cooperation will remain high.

Put simply, under the condition of a fixed partner, in any period \( t \), \( t \geq 1 \), it is proved that the size of pay-offs and the discount parameter impacts the stability of cooperation directly. Players will unilaterally defect for extra profit if it is large enough to make up the loss caused by a necessary defection in the future; otherwise, the Pareto Optimality (C, C) will be the equilibrium in every game.

4. Conclusions

In this paper, the authors have analyzed the stability of cooperation between owners and contractors based on a repeated game model with quantitative trust value as described above. In the model, the profit of defection and cooperation is compared to determine the motivation of defecting. During the calculation of profit, the loss and recovery of trust was depicted dynamically and mathematically in the trust model. It is apparent that defection leads to an immediate benefit, but results in a loss of trust. When the defector chooses to return to a cooperative mode, the lost credit could be recovered by changing partners.

Under the circumstance of changing partners after a defection, the analysis proved that the stability of cooperation has a negative correlation with the recovery velocity of trust (\( \nu \)) and the probability of undiscovered defection (\( \epsilon \)), and also has a positive correlation with the number of defections (\( N \)). The optimal number of defections is 1 for a defector, for any values of \( \nu \) and \( \epsilon \). If the pay-off of cooperation is large enough and the values of \( \nu \) and \( \epsilon \) satisfy a specific mathematical relationship, there would be no more profit in defections, thus reducing the motivation towards defections.

With a fixed partner, defection would cause an indefinite credit loss. Thus, if the present defection's extra profit is large enough to cover the future loss, the defection will happen; if not, the cooperation will remain stable.

This study shows that the stability of cooperation is impacted by many factors, such as strictness of supervision, information sharing in the market, and one partner's weighing of credit when choosing a partner. Hence, considering the existing reality of partners changing frequently, the factors mentioned require strengthening in order to maintain cooperative stability in the construction market. In addition, long-term cooperation with a fixed partner should be encouraged.

For the purpose of this research, the authors made several assumptions and simplifications to construct the model, and the authors acknowledge that these assumptions may be not entirely valid in practice.
These limitations should be overcome in future studies. The authors' future research will be primarily focused on two aspects:

(1) Improvements in the trust model. The possibility of trust recovery with a fixed partner will be discussed. Defectors may be treated as trustworthy again in the real world, a possibility that must be accounted for in future trust models.

(2) Situations in which players participate in the market for limited periods. Many partners may choose to leave the market at a certain time, again a factor, which must be incorporated in modeling.

In addition, future research should also quantitatively investigate the probability of undiscovered defection in a single game and the recovery velocity of trust.

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