Chapter 13
Research on the Construction Safety Investment Regulation Evolutionary Game and Application

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Abstract From the view of limited rationality, the interaction behavior between construction safety supervision departments and construction enterprises is analyzed based on evolutionary game theory. An evolutionary game model of the safety investment supervision in construction enterprise is established. The replication dynamic equation and the dynamic evolution process of the both gaming parties are analyzed. The behavior features of the two gaming parties and the affect to the stability status are revealed. The different kinds of evolutionary stability strategies are analyzed and the long-time stable tendency of construction safety investment supervision is predicted. Besides, the article provides empirical studies which prove that the model is more effective and verify the validity of the model. Article concludes with some policy recommendations. For construction enterprises safety investment and government supervision and management, the theoretical and methodological useful guide is provided.

Keywords Construction safety investment · Regulation · Evolution game · Stable strategy

13.1 Introduction

The healthy and sustainable development of construction industry is the important guarantee of economic development in China. For the construction industry, the ensurance of production safety is an important responsibility of the government and construction enterprises [11]. Construction safety situation of our country has

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J. Xu et al. (eds.), *Proceedings of the Eighth International Conference on Management Science and Engineering Management*, Advances in Intelligent Systems and Computing 280,
DOI: 10.1007/978-3-642-55182-6_13,

greatly improved through the efforts of government and enterprise in recent years, but currently there are still some problems of frequent safety accidents [5] and greater casualties [3]. For construction enterprises, the emphasis and implementation of safety investment is the prerequisite to actualize safety production, and it is also the important guarantee of realizing economic and social benefits and sustainable development. However, due to the high cost and low profit of construction enterprises, along with inadequate government supervision, they lead to the current construction enterprises not having enough impetus to implement security investment, which is difficult to guarantee the production and development of health and safety in construction enterprises. The government has always been attaching great importance to the safety production of the construction enterprises [8], conducting policy guidance and supervision to the construction enterprise' safety production and investment. But as the result of the inadequacy of the current management system and indicators for performance check, and the insufficiency of regulatory enforcement, combined with the current management without fully considering the bounded rationality, there still exists the phenomenon that the construction safety investment supervision is insufficient. One question which has remained to be urgently solved is how the government supervisory department effectively regulates, guides and motivates construction enterprise safety investment.

13.2 Analysis Framework

The decision-making of construction enterprise itself and the regulation of the government will influence the safety investment of construction enterprises. Shenling analyzed the supervisory strategies of construction safety investment with the method of game [7]. Zhao and Yang analyzed the supervision status of coal mine safety production of our country according to the theory of game, finding that the government can effectively improve the efficiency of governance by means of increasing penalties for illegal enterprises, reducing regulatory costs, and enhancing the supervision probability [10]. Cao and Wang analyzed the regulation of construction safety production in our country and put forward the relevant policy recommendations by using the theory of game [2]. There are a lot of researches on construction safety investment regulations in recent literature from the macroscopic and microscopic view and the qualitative and quantitative perspective. But currently the construction companies and the government are analyzed as a perfectly rational object in the main study, and the limited rationality of the construction enterprises and the government is not considered in the process of government regulation of construction enterprises safety investment. With consideration of the limited rationality of the government and enterprises, it is of great practical significance for the government to implement effective supervision and further to promote the construction safety investment and the safety production level. In the process of dealing with limited rationality game, evolutionary game [1] which is based on limited rationality [6] can effectively manipulate the evolutionary process of both sides, imitating gradually by

Table 13.1 One safety investment regulation game model of construction enterprises

Construction enterprise	Government regulator	
	Regulation x	No regulation $1 - x$
Safety investment y	$R - I$	$R - I$
	$-A$	0
Illegal production $1 - y$	$R - pL - qF$	$R - pL$
	$qF - A$	$-p(C + M)$

the most advantageous strategy, eventually reach an equilibrium state [4] and obtain the credible conclusions closer to the reality.

Therefore, the paper studies the regulation of construction safety investment applying the evolutionary game theory to help the government make a scientific and effective regulatory decision-making and system design in the process of government regulation. It is of great practical significance for the healthy and sustainable development of construction enterprises and to promote the implementation of construction enterprise safety investment more effectively.

13.3 Foundational Assumptions of Evolutionary Game Model of Safety Investment Regulation

For construction safety investment regulation, there is game between government regulators and construction companies, and the both sides have their own different strategy choice. As the government regulators, they can choose to supervise or not, while for construction enterprises correspondingly, they can choose to implement safety investment or not. The strategy and income of both sides are asymmetric on their different options, whose payoff matrix are shown in Table 13.1.

As is shown in the Table 13.1, the character A stands for government regulation costs. Due to the limitation of various conditions, government regulators can only implement regulation work with probability x. If the construction enterprises realize that the implementation of construction safety investment is of great importance for the stable and healthy development of the enterprise, the construction enterprises will implement safety investment without considering regulation or not, I standing for the safety investment cost. R stands for the comprehensive benefit obtained by construction enterprise in safety production, the probability of which is y. If construction enterprises ignore safety production and abandon safety production investment in order to get maximum benefit, p stands for probability for construction safety accident, L for the loss of the accident. F stands for penalty once the problems and accidents were discovered by government regulators, and q for the probability of being punished. If regulators do not supervise the safety production of the construction companies diligently, therefore construction companies do not pay attention to the construction safety investment. Once the safety accidents happened, which causes the social cost C, regulators can receive the penalty M caused by the superior government.

13.4 Analysis of Evolutionary Game of Construction Safety Investment Regulation

With the slow strategy study and slight headway of dynamic adjustment of construction safety investment and regulatory, the replication dynamics can be applied to study the interactive game of the construction safety investment regulation by using evolutionary game to analyze construction safety investment regulation [9].

13.4.1 Replication Dynamics and Stable Strategy of Evolutionary Game of Construction Safety Investment

From the Table 13.1, the return for the implementation of safety investment of construction enterprises is $u_1 = x(R-I)+(1-x)(R-I) = R-I$. The return without the implementation of safety investment of construction enterprises is $u_2 = x(R - pL-qF) + (1-x)(R-pL) = R-pL-xqF$. The average return for construction enterprise groups is $\bar{u} = yu_1 + (1-y)u_2 = y(pL - I + xqF) + R - pL - xqF$. The replication dynamic equation of construction enterprises on safety investment behavior is: $F(y) = \frac{dy}{dt} = y(u_1 - \bar{u}) = y(1-y)(pL - I + xqF)$.

Making $F(y) = \frac{dy}{dt} = 0$, the possible stable state is:

$$y_1 = 0,\ y_2 = 1,\ x = \frac{I - pL}{qF}. \tag{13.1}$$

As is known by the nature of the evolutionary stable strategy, when $F'(y^*) < 0$, y^* is the evolutionary stable strategy.

- When $x = \frac{I-pL}{qF}$, $F(y)$ is 0. At the moment, government's regulation reaching $x = \frac{I-pL}{qF}$, the initial ratio between implementation of safety production investment and no implementation of safety production investment in any construction enterprises is stable.
- When $x \neq \frac{I-pL}{qF}$, there are two balance points $y_1 = 0$, $y_2 = 1$, of Replication dynamic equation.
- When $x > \frac{I-pL}{qF}$, $F'(1) < 0$, that is $y_2 = 1$ which is the evolutionary stable strategy. After a long repeated game, limited rational construction enterprises choose to implement safety investment strategy to strengthen the importance of construction safety investment.

- When $x < \frac{I-pL}{qF}$, $F'(0) < 0$, that is $y_1 = 0$ which is the evolutionary stable strategy. After a long repeated game, limited rational construction enterprises choose not to implement safety investment strategy. In this case, the construction enterprises will gradually reduce emphasis on safety investment.

13.4.2 Replication Dynamics and Stable Strategy of Evolutionary Game of Government Regulation

From the Table 13.1, government regulators' return for supervision is $n_1 = y(-A) + (1-y)(qF - A) = (1-y)qF - A$. And government regulators' return without supervision is $n_2 = -p(1-y)(C+M) = p(y-1)(C+M)$. The average return of the government regulators is $\bar{n} = xn_1 + (1-x)n_2 = x[(1-y)qF - A] + (1-x)p(y-1)(C+M)$. Replication dynamic equation of government regulators is $H(x) = \frac{dx}{dt} = x(n_1 - \bar{n}) = x(1-x)[(1-y)(qF + pC + pM) - A]$.

Making $H(x) = \frac{dx}{dt} = 0$, the stable state is:

$$x_1 = 0, x_2 = 1, y = 1 - \frac{A}{qF + p(C+M)}. \tag{13.2}$$

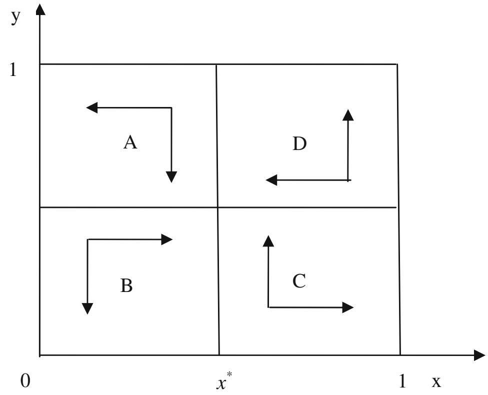
As is known by the nature of the evolutionary stable strategy, when $H'(x^*) < 0$, x^* is the evolutionary stable strategy.

- When $y = 1 - \frac{A}{qF+p(C+M)}$, $H(x)$ is 0. That is, when construction enterprises put safety investment value to $y = 1 - \frac{A}{qF+p(C+M)}$, the intensity of government regulation is stable.
- When $y \neq 1 - \frac{A}{qF+p(C+M)}$, replication dynamic equation has two balance points $x_1 = 0, x_2 = 1$.
- When $y > 1 - \frac{A}{qF+p(C+M)}$, $H'(0) < 0$, that is, $x_1 = 0$ is the evolutionary stable strategy. The construction enterprises actively implement the safety investment and government regulators have fewer regulations.
- When $y < 1 - \frac{A}{qF+p(C+M)}$, $H'(1) < 0$, that is, $x_2 = 1$ is the evolutionary stable strategy. In this case, limited rational construction enterprises choose not to implement safety investment strategy and government regulators actively implement safety regulation.

13.5 Game Theory Analysis

Making $x^* = \frac{I-pL}{qF}$, $y^* = 1 - \frac{A}{qF+p(C+M)}$. As is shown in Fig. 13.1, the replication dynamic and game tendency of security investment regulation in construction companies and government regulators are drawn.

Fig. 13.1 Construction safety supervision game phase diagram



Government regulator and construction companies both are not have the only dominant strategies, the system' converge depends on its initial state. When the initial strategy falls into area A, construction companies would choose "implementation of safety investment" strategy, and government regulators select "no regulation" strategy. But this relationship is not stable. In fact, if government regulators select "no regulation" strategy, then the construction enterprises will tend to choose "not to implement" strategies. It will lead the strategic profile to fall into the area B, in which government regulators choose "no regulation" strategy and construction enterprise choose "not to implement" strategies. Because groups will gradually adjust their strategies by mutual learning in B region, this state is not stable obviously. When government regulators realized that construction companies select "not to implement" strategies, they will gradually adjust their strategy to fall into the area C, in which government regulators will choose "regulation" strategy. In this case, faced with the "regulation" strategy, construction companies will gradually adjust their strategy to fall into the area D, in which the construction companies select "implementation of safety investment" strategy and government regulators choose "regulation" strategy. In this case, government regulators found that construction companies have chosen "implementation of safety investment strategy", they will gradually adjust their strategy to fall into "no regulation" strategy which is the area A. The cycle of the preceding process continues.

Firstly, for the government regulator, the increase of regulatory cost A will make y^* decrease, which causes construction enterprises to attach less importance to construction safety investment. For another, with the increase of C and M, y^* will increase. Government regulators will enhance supervision intensify and probability under the pressure from social expectations and the superior government.

Secondly, for construction companies, when the government supervision probability satisfies $x > x^*$, construction enterprises will attach greater importance to the safety investment; if F increases, y^* will also go up. That is, construction enterprises will attach more importance to construction safety investment when regulators

Table 13.2 Strategies of safety investment regulation for construction enterprises

Construction enterprises	Government regulator	
	Regulation	No regulation
Safety investment	1,200	1,200
	−200	0
Illegal production	1,010	1,360
	150	−360

give them more punishments. Of course, the increase of R will lead to the increase of I and the decrease of F. If construction enterprises increase construction safety investment, they will enhance the comprehensive benefits R, meanwhile, reduce the negative benefits F, which makes the government regulation intensity will also be reduced.

13.6 Calculation Case Analysis

The government regulatory cost A is 2 million yuan. The cost I of construction enterprise safety investment is 8 million yuan, while the comprehensive benefits R of construction enterprise safety production are 20 million yuan. The probability p of accidents should be 0.8 when the investment of safety production is not implemented by construction enterprises and the loss L after the accident is 8 million yuan. The penalties F will be 5 million yuan once the accident is found by the government regulators with the probability $q = 0.7$. If the construction enterprises do not implement the construction safety investment because of the shortage of the government supervision, the social cost C will arrive at 300 million yuan caused by the accidents, and the penalties M on regulators are 150 million yuan caused by the superior government. The government regulator and construction enterprises game model are shown in Table 13.2.

Data below can be calculated according to the Eq. (13.1): $x = \frac{I-pL}{qF} = \frac{800-0.8\times 800}{0.7\times 500} = 0.46$. From the Eq. (13.2), we can obtain: $y = 1 - \frac{A}{qF+p(C+M)} = 1 - \frac{200}{0.7\times 500+0.8(300+150)} = 0.72$.

From the model analysis we can make a conclusion that when government's regulation reaching $x = 0.46$, the initial ratio between implementation of safety production investment and no implementation of safety production investment in any construction enterprises is stable.

- When $x > 0.46$, after a long repeated game, limited rational construction enterprises choose to implement safety investment strategy to strengthen the importance of construction safety investment.
- When $x < 0.46$, after a long repeated game, limited rational construction enterprises choose not to implement safety investment strategy. In this case, the construction enterprises will gradually reduce emphasis on safety investment.

For construction enterprise, when construction enterprises put safety investment value to $y = 0.72$, the intensity of government regulation is stable.

- When $y > 0.72$, The construction enterprises actively implement the safety investment and government regulators have fewer regulations.
- When $y < 0.72$, limited rational construction enterprises choose not to implement safety investment strategy and government regulators actively implement safety regulation.

13.7 Conclusions

It is the important guarantee for construction enterprises sustainable development to make effective supervision on construction safety investment. From the view of limited rationality, the interaction behavior between construction safety supervision departments and construction enterprises is analyzed based on evolutionary game theory. An evolutionary game model of the safety investment supervision in construction enterprise is established. The behavior features of the two gaming parties and the affect to the stability status are revealed. The different kinds of evolutionary stability strategies are analyzed and the long-time stable tendency of construction safety investment supervision is predicted. For construction enterprises safety investment and government supervision and management, the theoretical and methodological useful guide is provided. Based on the research result of this paper, we can make the conclusion and the policy suggestions as follows:

1. To make the entire construction industry health and sustainable development, the government should strengthen the supervision and punish illegal enterprises severely by legislation to make sure the safety investment.
2. The supervision departments of the government should keep on improving the efficiency of supervision and reducing the cost of supervision including the running cost of the regulator.
3. The cost of construction enterprises who never comply with the safety production of construction and implement safety investment should be increased by policy and regulation. Meanwhile, the cost of safety investment should be decreased to lead and impel construction enterprises to implement the safety investment.
4. The assessment and the accountability system of supervision department should be strengthened; meanwhile the public should be encouraged to actively participate in supervision. The supervision is not only for the construction enterprises but also for the government regulator.

Acknowledgments The research is funded by "The Department of Education Project of Sichuan Province (14SB0022): Research on Enterprise Safety Investment System Analysis and Multi-regulatory Game", "Sichuan Province, Philosophy and Social Science Research Base—Sichuan Mineral Resources Research Center Funded Projects (SCKCZY2012-YB005)" and "The Department of Education Key Project of Sichuan Province (14ZA0026)" and "The Sichuan Normal University Project (14yb18)".

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