

Article

Countermeasures for the Transformation of Migrant Workers to Industrial Workers in the Construction Industry Based on Evolutionary Game Theory

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Abstract: With the rapid development of new construction methods, China's construction industry is facing the transformation challenges of industrialization and informationization. However, migrant workers are characterized by high mobility, low education, and poor skills in China's national conditions, which can no longer meet the requirements of operations. The transformation of the low-level manual migrant workers in the construction industry to high-level skilled industrial workers is inevitable. In order to explore how to better achieve the transformation of construction workers, evolutionary game research with construction unit and labor company as the subjects was carried out. Three types of assumptions were introduced into the constructed evolutionary game model: cooperation mechanism, spillover effect, and incentive mechanism (CSI). Simulation experiments and analysis of the model were finally conducted. The results of the game analysis finally show: (1) a higher initial proportion of selected transformed industrial workers; (2) a fair benefit concession from the construction unit to the labor company; (3) a lower revenue spillover effect; (4) that a higher level of regulation and incentives are conducive to the evolutionary game to converge to the desired state at a faster rate. The findings provide ideas for improving the labor system in China's construction industry and lay the foundation for solving the labor specialization problem of new construction methods.



Citation: Guo, F.; Guo, M.; Li, Y.; Gu, J. Countermeasures for the Transformation of Migrant Workers to Industrial Workers in the Construction Industry Based on Evolutionary Game Theory. *Buildings* **2023**, *13*, 2985. <https://doi.org/10.3390/buildings13122985>

Academic Editor: Paulo Santos

Received: 3 November 2023

Revised: 27 November 2023

Accepted: 28 November 2023

Published: 29 November 2023



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Keywords: construction; migrant workers; industrial workers; transformation; evolutionary game; simulation analysis

1. Introduction

In the background of high-quality economic development, the construction industry, as a pillar industry of China's national economic development, is facing the challenge of construction intelligence, product greening, and management refinement transformation. The traditional construction industry is characterized by sloppy, inefficient, and high consumption [1]. A large part of this situation is due to the uneven quality of migrant workers in construction industry are difficult to manage, which leads to chaotic management of the construction site [1]. According to the standards of the National Bureau of Statistics of China, migrant workers are defined as those whose household registration is still in the countryside and who have been engaged in non-agricultural industries locally or have been working away for six months or more during the year [2]. According to the China National Bureau of Statistics "2022 Migrant Worker Monitoring Survey Report", the proportion of those engaged in the construction industry is 17.7% among the group of migrant workers. This represents a decrease of 1.3% from the previous year [3]. Due to the rise of new construction methods such as smart construction, green construction, and prefabricated building, the construction industry shifts from relying heavily on manual labor and traditional technical skills to relying more on information technology and spe-

cialized skills. This trend facilitates the transformation of construction migrant workers to industrial workers [4].

China's construction industry has a large volume and high labor demand [5]. Since its development, China's construction industry has faced the dual challenges of transformation and upgrading and going global [6]. To make more migrant workers to industrial workers is the key tasks of current construction industry transformation of high-quality development [7]. Through this transformation, a group of industrial workers with high skill quality and professionalism can be cultivated, which can help the construction projects to improve the level of construction work, facilitate the management of the project site, and improve the quality of the project. Overall, the transformation of industrial workers can help in the following three ways. At the micro-project level of the construction industry, construction workers are prompted to industrialize in order to implement responsibilities, regulate behaviors, and improve operating standards [8]. At the meso-construction level, a stable industrial workforce is a prerequisite for the healthy development of the construction industry [9]. At the macro-social level, transformation from traditional migrant workers into industrial workers is prominent for realizing labor force change and building socialism with Chinese characteristics in the new era [10]. To sum up, it is crucial to improve the traditional labor model and promote the industrialization of construction workers in China's construction industry. In actuality, this is an effective way to realize the refined management of projects, the high-quality development of the construction industry, and the transformation of the social workforce.

In addition, for migrant workers, transformation contributes to job stability, social equality, professionalization, and protection of their rights and interests. For a construction unit and labor company, transformation enables them to get a group of skilled and high-quality construction workers. Ultimately, the rights and responsibilities are clearly defined and the quality of completion is guaranteed [11]. In recent years, the State Council of PRC has issued the "Reform Program for the Construction of Industrial Workforce in the New Period" [12]; "Guiding Opinions on Accelerating the Cultivation of the Construction Industrial Workforce in the New Era" [13] intended to cultivate a high-quality, skilled, and innovative construction industrial workforce from the perspective of top-level design. At the same time, these documents aim to promote the reform of the labor system in the construction industry from the traditional low-level manual migrant workers to the emerging high-level skilled industrial workers [11].

The discussion of construction worker industrialization transformation roughly includes the following three aspects. First, research on the establishment of a construction industry workforce, which considers what factors can solve the current dilemma. The research subject is the influencing factors of the industrial workers team construction. Jiang and Yan studied the dilemma of the construction industry workers team construction and put forward corresponding countermeasures suggestions [14,15]. Chen and Liu then demonstrated the evolution path of the labor system in the construction industry and the important role of labor system reform in building the industrial workforce [16,17]. Wang and Liu et al. discussed how to cultivate and manage the industrial workforce in the new era, and made it clear that vocational education is an important path to promote the construction of the industrial workforce [18–20]. Zhu and Wang relied on China's labor force dynamics data to analyze the influencing factors of the willingness and process of citizenship of migrant workers in the construction industry [21,22].

Second is the research on the influencing factors of the industrialization transformation of migrant workers in the construction industry, which considers the influence of external factors on the industrialization transformation of migrant workers. The research subject is the influencing factors of the transformation of migrant workers to industrial workers. Li and Zhu identified the key constraints on the cultivation of industrialized workers of migrant workers from the background of construction industrialization [23,24]. Ren showed that the degree of professionalization of migrant workers in the construction industry is the direct driving factor for their transformation into industrial workers [25].

Zhu and Du analyzed the motivating factors for the transformation of migrant workers in the construction industry into industrial workers, and put forward suggestions for transformation [26,27].

Third, the construction industry migrant workers to industrial workers transformation evolution research considers the transformation process of various types of subjects in the decision-making evolution mechanism. The research subject is an evolutionary decision game which transforms considering various influencing factors. Ke discussed the complexity and emergence of the evolutionary process of industrialization of migrant workers in the construction industry based on the CAS theory [28]. Su constructed the game evolution model between local governments and labor enterprises, then analyzed the dynamic interest relationship and behavioral decision-making mechanism of the two in the process of industrial worker training [29]. To sum up, the existing studies demonstrated the importance of establishing industrial workers, put forward measures for the cultivation and management of industrial workers, and analyzed and put forward the influencing factors and safeguard measures for the transformation of migrant workers to industrial workers. However, there is still a lack of research on the intrinsic evolution mechanism of the transformation from migrant workers to industrial workers in the construction industry, which exists between different types of enterprise subjects and stakeholders in the construction industry.

The “migrant labor problem” is a unique social phenomenon in China that emerged during the period of social transformation. However, research on this topic remains limited. More generally, scholars mainly analyzed the problem of construction labor from the perspectives of construction labor demand, rural labor transfer, and the transformation of construction workers, but seldom studied the transformation of migrant workers in China’s construction industry. On the one hand, the issue of labor employment in the construction industry was studied from the urban–rural migration of construction workers, worker safety, and labor rights protection [30–34]. Wan, Jin, and Zhang proposed mechanisms and measures to protect the labor rights and interests of migrant workers in China’s construction industry [35–37]. Kazaz provided a study on the factors influencing the productivity of construction workers in Turkey [38]. Brunette, Cheng, and Gatti proposed methods to monitor the physiological conditions and unsafe behaviors of construction workers in order to reduce injuries and promote safety and decency [39–42].

On the other hand, the research focused on the dualistic socio-economic structure and principles of population migration to analyze the transfer of surplus rural labor [43–45]. Guang studied the knowledge transformation of individual human capital of Chinese laborers based on machine learning and artificial intelligence [46]. Bover constructed a model of labor demand in the construction industry [47]. In order to effectively match the information of employment demand with rural surplus labor and reduce the hidden and unsoundness of rural labor transfer, Wang introduced the design of an information platform for training and employment of migrant workers [48]. Buckley explored the impact of widespread flexibility trends on the international construction labor market and highlights the intersectionality of these trends with the growing number of temporary migrant labor in recent decades [49]. Najib analyzed the factors influencing the participation of the local construction labor force in construction in Malaysia [50]. Baral studied the impact of the COVID-19 pandemic on the U.S. construction labor market [51].

In addition, some scholars researched the influencing factors and training measures for the transformation of migrant workers to industrial workers in China’s construction industry. Ke interpreted seven indicators of the compatibility of construction migrant workers with the CAS theory [52]. Yang constructed a theoretical model influencing the industrialization intention of construction migrant workers and explored the key factors and cognitive mechanisms of their transformation to industrial workers in the construction industry [53]. Ke established a structural equation model of the transformation mechanism of construction migrant workers to industrial workers and provided policy recommendations for promoting transformation through appropriate training [54]. In summary, existing

studies focused on improving the productivity and security of construction workers, then proposed a series of measures to solve the problem. The results of informatization monitoring and training and employment information platforms in the research are useful for the transformation of migrant workers to industrial workers in China's construction industry. However, the research on the reform of the employment system in the construction industry is relatively weak. In particular, the "migrant worker problem" has not been analyzed and discussed, which affects the process of informatization and refinement of China's construction industry.

Current research has not yet taken into account the heterogeneity of the multiple parties involved in the transformation. There are few research results on the cooperation between construction unit and labor company. In the cooperation between construction unit and labor company, both parties often have bounded rationality and are limited by their decision-making ability. It is difficult for both parties to make the optimal decision in a very short time. However, they can constantly revise and optimize decisions through observation, learning, and comparison. Evolutionary game theory emphasizes bounded rationality and dynamic equilibrium [55]. Construction unit and labor company can compare and adjust according to each other's dynamic strategy [56]. Therefore, the method of evolutionary game is adopted in the research. Evolutionary game research in the field of engineering management includes the following: Su et al. analyzed the dynamic interest relationship and behavioral decision-making mechanism between the two in the process of industrial workers training [29]; Shi et al. proposed an evolutionary game model and analyzed the key factors affecting the suppliers' tendency to cooperate [57]; and Li et al. explored the internal cooperation mechanism of PPP projects [58].

From the above analysis, promoting the industrialization of construction workers is crucial in China's construction industry. Existing research contributes to the influence factors of transformation transition and the building of industrial workers. However, few scholars analyzed in depth the internal evolutionary mechanism of the transformation from migrant workers to industrial workers in the construction industry. Moreover, no research has been carried out on the reform of the labor system for the subject of different construction industry enterprises.

Regarding these insufficiencies, this paper aims to examine how different construction firms make decisions about their labor practices. The main objective of this paper is to analyze the decision-making process of transforming labor practices in different firms. Thereby, measures that can effectively motivate firms to choose to transform industrialized workers are proposed. Specifically, this study first analyzes the stakeholders of industrial workers' decision to transform. Secondly, the model is constructed according to the evolutionary game theory, which introduces the CSI assumptions. Finally, the MATLAB R2021b (9.11.0.1769968) platform is used to carry out simulation to explore the conditions and its equilibrium state for both construction units and labor companies to realize the transformation of migrant workers to industrial workers. The research results enrich the theoretical study on the transformation of migrant workers into industrial workers in the construction industry. At the practical level, this study provides construction enterprise and labor company with policy suggestions for transforming migrant workers in the construction industry into industrial workers based on the CSI mechanism.

The remainder of this paper is structured as follows. The next section describes the construction of an evolutionary game model and the analysis of the equilibrium state of the system. Furthermore, simulation experiments were conducted to verify the effects of various parameters on the subjects' decisions. Next, based on simulation results, both theoretical and practical implications are concluded. Finally, conclusions, limitations, and future research are discussed.

2. Methodology

The theoretical framework of this study consists of three parts, as shown in Figure 1. The first part is to analyze the relationship between the relevant subjects of the evolutionary

game utilizing the stakeholder theory. In view of this, the basic assumptions of the model and the CSI assumptions are proposed. Then the parameters are set and the parameters are used to analyze the evolutionary game payoff matrix and the replicator dynamic equation. The second part is to determine the range of values of the dependent variable and each parameter in conjunction with the characteristics of the values of the independent variables in the replicator's dynamic equations. This makes a preliminary analysis of the evolutionary equilibrium state of the system and the influence of parameter changes. Finally, numerical simulations are performed using MATLAB in order to explore the effect of the initial ratio of transformation on the equilibrium point of the system. A sensitivity analysis, which is used to probe the impact of the CSI mechanisms on the system evolution, was also performed.

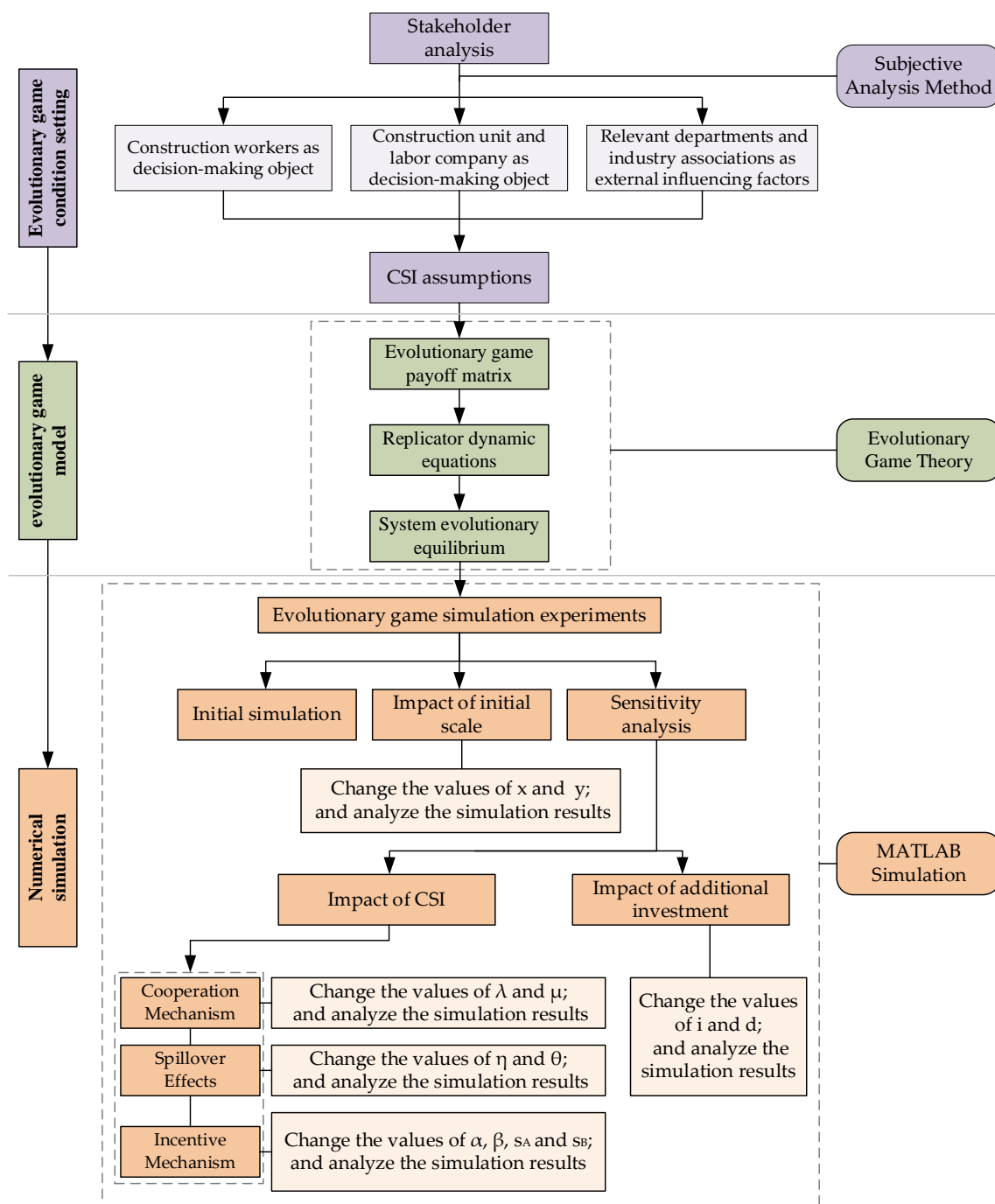


Figure 1. The theoretical framework. Note: Drawing made using Microsoft Visio Professional 2016.

2.1. Evolutionary Model

2.1.1. Stakeholder Analysis

As shown in Figure 2, the stakeholders of the evolutionary system are divided into three categories in this study: decision object, decision subject, and external influencing factors. The decision object is construction workers, and there are two types: migrant workers and industrial workers. The decision-making subject is the construction unit and the labor company, which make direct decisions in the two types of decision-making objects. External influencing factors affect the decision-making subject to make decisions.

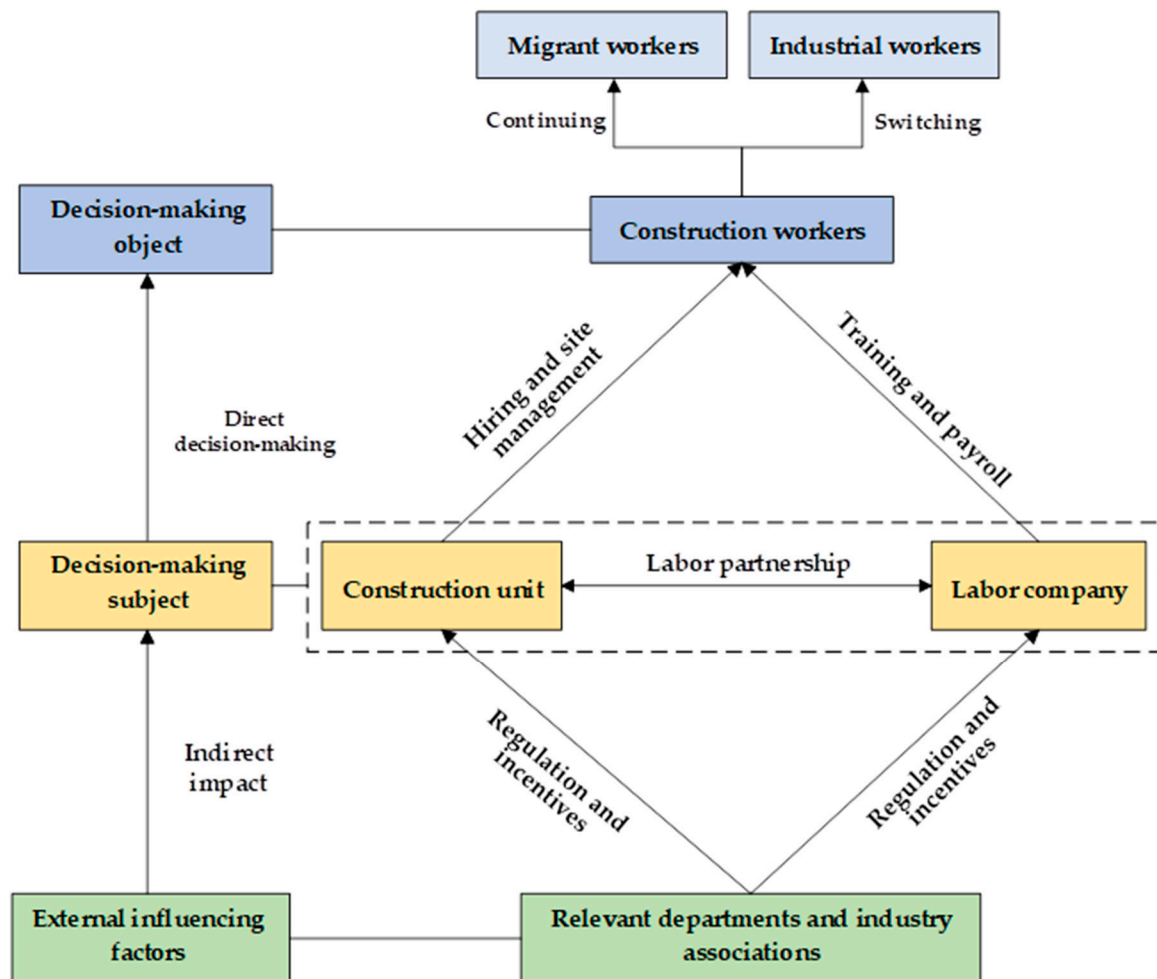


Figure 2. Relationships of the stakeholders in the evolutionary game. Note: Drawing made using Microsoft Visio Professional 2016.

1. Decision-making object: construction workers. There are generally two types of construction workers: migrant workers and industrial workers. Migrant workers in the construction industry are a group of people whose household accounts are in rural areas, while their main source of income is through performing construction labor, technical work, or construction management at construction sites [59]. Compared with traditional construction migrant workers, industrial workers are able to master modern professional skills. Their wages, working conditions, and safety can be effectively guaranteed. They generally represent the advanced productivity of the construction industry [60].
2. Decision-making subject: construction unit and labor company. Construction workers are generally dispatched by the labor company to the construction unit project site operations in the labor market circulation. Their wages are issued by the labor

company, but the place of operation is at the project site of the construction unit. Therefore, they are dually constrained by the labor company and the construction unit's on-site project department. The construction unit and the labor company need to make a decision between switching to using industrial workers and continuing to use migrant workers. The transformation of construction workers from less skilled migrant workers to skilled industrial workers requires training provided by the construction labor company, which generates an investment in training. Instead, the construction unit is responsible for hiring, and it incurs incremental labor costs. This makes it possible to guarantee the quality of the corresponding completion and to minimize potential risk losses.

3. External influencing factors: relevant departments and industry associations. The relevant departments of the construction industry and industry associations encourage the transformation of the employment system from migrant workers to industrial workers. The measures they take include the promulgation of policies, standardization, and the development of norms. Moreover, certain incentives are given, such as the awarding of advanced enterprise awards in the industry, giving cash prizes, and tilting resources. Such incentives are not 100% covered. They are related to the probability of supervision by the relevant departments and industry associations. There is undeniably some influence on the decision-making subject (construction unit and labor company) to make strategic choices.

2.1.2. CSI Mechanism Assumptions and Parameters

1. Assuming that the two parties of the evolutionary game are the construction unit (A) and the labor company (B), their strategy space is $S_{1,2} = (\text{switching to using industrial workers, continuing to use the migrant workers})$. The strategy choice and dynamic adjustment of evolutionary game subjects follow the rule of finite rationality. In group A, the proportion of construction unit choosing transformed industrial workers is x . In group B, the proportion of labor companies choosing transformed industrial workers is y . The normal profit of the construction unit in using migrant workers along is π_A . If the construction unit chooses to switch to industrial workers, it will spend I_A on the transition hiring investment and will receive R_A in transition benefit income ($R_A > I_A$). The labor company's normal profit at the low standard is π_B . If the labor firm chooses to switch to industrial workers, it will spend I_B investment on transition training investments and will receive R_B in transition benefit income ($R_B > I_B$).
2. The cooperation mechanism is introduced into the evolutionary game model. The transformation of migrant workers into industrial workers is regarded as the cooperation process of "benefit sharing and investment sharing" between construction unit and labor company. If they choose to transform into industrial workers, the construction unit will transfer a certain proportion of the income gained from the transformation to labor company ($R_B = \lambda R_A$). Correspondingly, the labor company will also bear a certain proportion of the investment in transformation training ($I_B = \mu I_A$). When the labor company chooses to switch to industrial workers but the construction unit does not, the labor company is unable to receive transition benefit cession from the construction unit, even if it pays for complete transition training investment. When the construction unit chooses to switch to industrial workers but the labor company does not, the construction unit will support the strategic choice through a series of measures. These measures may include increasing the wages of industrial workers, or implementing training activities for them to improve their skills and qualifications. These cost additional transformational investment I_C .
3. A spillover effect is introduced into the evolutionary game model. Certain externalities exist in the transformation of migrant workers into industrial workers, namely the "free-rider" effect. Strategy subjects can still earn transition income at some level, even if they do not choose to switch to industrial workers. For example, they suppress the

wages of migrant workers and directly employ workers who have been trained at high salaries. However, this spillover effect is very unstable. Strategy subjects cannot obtain all the benefits with certainty. Therefore, the transformation revenue spillover factor of construction unit and labor company is assumed to η and θ , which range from 0 to 1. In addition, when both the construction unit and labor company choose to use migrant workers, the labor company cannot get the income spillover.

4. An incentive mechanism is introduced into the evolutionary game model. Relevant departments and industry associations regulate construction unit and labor company. If construction unit chooses to switch to industrial workers, it may be supported by incentives from relevant departments and industry associations, the amount of which is S_A . If labor company chooses to switch to industrial workers, it may be supported by incentives from relevant departments and industry associations, the amount of which is S_B . However, the intervention is uncertain due to the high cost of supervision, market uncertainty, and technical limitations. The regulation and rewards occur only with a certain probability. Therefore, the probability is assumed to be α and β accordingly that the relevant departments and industry associations intervene in the construction unit and labor company.

Under the conditions of limited rationality and information asymmetry, the construction unit and labor company will choose the maximizing behavioral decision in the strategy set. There is a certain probability of adjusting the strategy. Based on the above four types of assumptions, this study analyzes the strategy evolution process of construction unit and labor company in choosing to switch to industrial workers. Specifically, the research question is whether the initial parameters $\lambda, \mu, \eta, \theta, \alpha, \beta, s_A, s_B, i$, and d affect the subject's decision under the CSI mechanism. The main issue of the study is their impact on the subject's decision making and the outcome of the evolutionary game. Ultimately, it is proposed that certain measures should be taken to promote the evolutionary game outcome to a desired positive state.

2.1.3. Payoff Matrix and Replicator Dynamic Equations

Construction unit and labor company play different roles in the transformation from industrial workers to migrant workers. They have different conflicts of interest and decision-making considerations. Based on the above assumptions and parameter settings, the benefits under different strategic choices of construction unit and labor company are listed. The payoff matrix is shown in Table 1.

Table 1. Evolutionary game payoff matrix.

Strategic Choice		Labor Company B	
		S_1 Switching to Using Industrial Workers (y)	S_2 Continuing to Use Migrant Workers ($1 - y$)
Construction Unit A	S_1 Switching to using industrial workers (x)	$\pi_A + R_A - I_A + \alpha S_A$ $\pi_B + R_B - I_B + \beta S_B$	$\pi_A + R_A - I_A - I_C + \alpha S_A$ $\pi_B + \theta R_B$
	S_2 Continuing to use migrant workers ($1 - x$)	$\pi_A + \eta R_A$ $\pi_B - I_B + \beta S_B$	$\pi_A + \eta R_A$ π_B

According to evolutionary game theory, if the fitness of a strategy is higher than the mean population fitness, the selection proportion for this strategy will gradually increase in the population. The growth rate is given by the replicator dynamic equations. The higher the value of replicator dynamics, the greater the growth rate of the selection proportion for the strategy [61,62]. Based on the above payoff matrix, the average adaptation (expected return) can be calculated for construction unit (A). They are U_{A1} , U_{A2} , and U_{AE} for switching

to using industrial workers (S_1), continuing to use migrant workers (S_2), and the mixed strategy, respectively, as shown in Equations (1)–(3):

$$U_{A1} = y(\pi_A + R_A - I_A + \alpha S_A) + (1 - y)(\pi_A + R_A - I_A - I_c + \alpha S_A) \quad (1)$$

$$U_{A2} = y(\pi_A + \eta R_A) + (1 - y)(\pi_A + \eta R_A) \quad (2)$$

$$U_{AE} = xU_{A1} + (1 - x)U_{A2} \quad (3)$$

A replicator dynamic equation $F_A(x)$ is constructed where the construction unit chooses to switch to industrial workers, as in Equation (4). In particular, let $G_A(y)$ be the function of the proportion y in the population for ease of the subsequent discussion and analysis, as shown in Equation (4). When $G_A(y)$ equals 0, y is equal to y^* :

$$F_A(x) = \frac{dx}{dt} = x(U_{A1} - U_{AE}) = x[U_{A1} - xU_{A1} - (1 - x)U_{A2}] = x(1 - x)(U_{A1} - U_{A2}) = x(1 - x)G_A(y) \quad (4)$$

$$G_A(y) = (1 - \eta)R_A - I_A + \alpha S_A + (1 - y)(-I_c) \quad (5)$$

At the same time, the average adaptation (expected return) can be calculated for labor company (B). They are U_{B1} , U_{B2} , and U_{BE} for switching to using industrial workers (S_1), continuing to use migrant workers (S_2), and the mixed strategy, respectively, as shown in Equations (6)–(8):

$$U_{B1} = x(\pi_B + R_B - I_B + \beta S_B) + (1 - x)(\pi_B - I_B + \beta S_B) \quad (6)$$

$$U_{B2} = x(\pi_B + \theta R_B) + (1 - x)\pi_B \quad (7)$$

$$U_{BE} = yU_{B1} + (1 - y)U_{B2} \quad (8)$$

A replicator dynamic equation $F_B(y)$ is constructed that labor company chooses to switch to industrial workers, as shown in Equation (9). Particularly, let $G_B(x)$ be a function of the proportion x in the population for the sake of subsequent discussion and analysis, as shown in Equation (10). When $G_B(x)$ is equal to 0, x is equal to x^* :

$$F_B(y) = \frac{dy}{dt} = y(U_{B1} - U_{BE}) = y[U_{B1} - yU_{B1} - (1 - y)U_{B2}] = y(1 - y)(U_{B1} - U_{B2}) = y(1 - y)G_B(x) \quad (9)$$

$$G_B(x) = x(1 - \theta)R_B - I_B + \beta S_B \quad (10)$$

2.2. System Evolutionary Equilibrium

2.2.1. Determination of Value Range

To analyze the stability of the evolutionary game model, a discussion is necessary to for the value range of $G_A(y)$, $G_B(x)$ and other parameters. The value range is determined according to definitional domain characteristics of x and y (located between 0 and 1). This study gradually adds conditions to the original model of the evolutionary game to observe the change of key parameters.

1. Under the condition of no spillovers and no incentives, it can be obtained that $0 \leq R_A - I_A \leq I_C$, $0 \leq R_B - I_B$. The amount of income is greater than investment for switching to industrial workers ($0 \leq R_i - I_i$), which is consistent with the basic assumption of this paper. Furthermore, the link indicates that the additional investment I_C is greater than normal benefit to support transition strategy choice in a specific way for the construction unit.
2. Conditional on spillovers and no incentives, it follows that $\eta R_A \leq R_A - I_A \leq I_c + \eta R_A$, $\theta R_B \leq R_B - I_B$. The link indicates that spillover effect of the transition income is smaller than the normal transition benefit ($\epsilon R_i \leq R_i - I_i$). Moreover, it can also be initially judged that the spillover effect coefficient is a small value between 0 and 1.

3. Conditional on spillovers and incentives, it follows that $\eta R_A \leq R_A - I_A + \alpha S_A \leq I_c + \eta R_A$, $\theta R_B \leq R_B - I_B + \beta S_B$. The link indicates that increase in the probability of regulation (α, β) and incentives S_i can raise the relative returns of transition when the relevant departments and industrial association intervene.

From $\eta R_A \leq R_A - I_A + \alpha S_A \leq I_c + \eta R_A$, we get $G_A(0) \leq 0, G_A(1) \geq 0$, as shown in Equations (11) and (12). From $\theta R_B \leq R_B - I_B + \beta S_B$, we get $G_B(0) \leq 0, G_B(1) \geq 0$, as shown in Equations (13) and (14). As a result, this paper derives the positive and negative cases of $G_A(y)$ and $G_B(x)$ when S_1 and S_2 are used as pure strategy choice. The cases play an important role in the subsequent judgment of stability and local equilibrium points in the evolutionary game model.

$$G_A(y=0) = (1-\eta)R_A - I_A + \alpha S_A - I_c \leq 0 \quad (11)$$

$$G_A(y=1) = (1-\eta)R_A - I_A + \alpha S_A \geq 0 \quad (12)$$

$$G_B(x=0) = \beta S_B - I_B \leq 0 \quad (13)$$

$$G_B(x=1) = (1-\theta)R_B - I_B + \beta S_B \geq 0 \quad (14)$$

2.2.2. Balanced Stability Analysis

According to the stability theorem of differential equations, whether a certain equilibrium point is an evolutionarily stable strategy (ESS) can be determined by the eigenvalues of the Jacobi matrix of a set of differential equations. Certain local equilibrium points satisfy that the determinant of the Jacobi matrix ($\det J$) is greater than zero and the trace ($\text{tr} J$) is less than zero, as shown in Equations (15) and (16). Then, it is a stable strategy of an evolutionary game [62,63]. Combined with the above analysis, we can obtain the Jacobi matrix, determinant and trace.

$$\det J = a_{11}a_{22} - a_{12}a_{21} \quad (15)$$

$$\text{tr} J = a_{11} + a_{22} \quad (16)$$

Evolutionary game steady state analysis is shown in Table 2. When $F_A(x) = 0$, $F_B(y) = 0$, the five local equilibrium points of evolutionary game can be obtained as $(0, 0)$, $(0, 1)$, $(1, 0)$, $(1, 1)$, (x^*, y^*) in the plane $M = \{(x, y) | 0 \leq x, y \leq 1\}$. According to the judgment condition of ESS, the following conclusions can be drawn: $(0, 0)$ and $(1, 1)$ are stable strategies of the evolutionary game, $(0, 1)$ and $(1, 0)$ are unstable points, and (x^*, y^*) is a saddle point.

Table 2. Evolutionary game steady state analysis.

x	y	a_{11}	a_{12}	a_{21}	a_{22}	$\det J$	+/-	$\text{tr} J$	+/-	State	p
0	0	$G_A(0)$	0	0	$G_B(0)$	$G_A(0)G_B(0)$	+	$G_A(0) + G_B(0)$	−	ESS	O
0	1	$G_A(1)$	0	0	$-G_B(0)$	$-G_A(1)G_B(0)$	+	$G_A(1) - G_B(0)$	+	UNS	U
1	0	$-G_A(0)$	0	0	$G_B(1)$	$-G_A(0)G_B(1)$	+	$-G_A(0) + G_B(1)$	+	UNS	V
1	1	$-G_A(1)$	0	0	$-G_B(1)$	$G_A(1)G_B(1)$	+	$-G_A(1) - G_B(1)$	−	ESS	W
x^*	y^*	0	H	L	0	$-H^* \times L$	−	0		SAD	S

Note: $H = x^*(1-x^*)(\beta F_B - I_c)$; $L = y^*(1-y^*)(1-\theta)R_B$; UNS stands for Unstable and SAD stands for Saddle point.

The following inferences can be drawn from the steady state analysis of the evolutionary game: (1) When $y = y^*$ ($0 \leq y^* \leq 1$), there is always $F(x) = 0$. Regardless of how to take the value in the definition domain x , the system can reach the evolutionary stable state. When the proportion of the labor company choosing to switch to industrial workers is y^* , there is no difference in construction unit's decision on its benefit. When $x = x^*$ ($0 \leq x^* \leq 1$), there is always $F(y) = 0$. Regardless of how to take the value in the

definition domain y , the system can reach an evolutionary stable state. When the proportion of the construction unit choosing to switch to industrial workers is x^* , there is no difference between the labor company's choice on its benefit. (2) When $y > y^*$, there is $G_A(y) > 0$. At this time, $x = 0$ and $x = 1$ are two possible stabilizing points. While $x = 1$, there is $\partial F_A(x)/\partial x < 0$. The evolution game can reach the stable state. Therefore, $x = 1$ is the only possible stable point. The employment method strategy of the construction unit gradually shifts from using migrant workers to industrial workers. Finally, switching to using industrial workers becomes the construction unit's evolutionary stable strategy. Similarly, when $y < y^*$, $x = 0$ is the only possible stabilization point. The strategy of continuing to use migrant workers becomes construction unit's evolutionary stable strategy. (3) When $x > x^*$, there is $G_B(x) > 0$. At this time, $y = 0$ and $y = 1$ are two possible stabilizing points. While $y = 1$, there is $\partial F_B(y)/\partial y < 0$. The evolution game can reach the stable state. Therefore, $y = 1$ is the only possible stable point. The employment method strategy of the labor company gradually shifts from using migrant workers to industrial workers. Finally, switching to using industrial workers becomes the labor company's evolutionary stable strategy. Similarly, when $x < x^*$, $y = 0$ is the only possible stabilizing point. The strategy of continuing to use migrant workers becomes the labor company's evolutionary stable strategy. (4) Accordingly, the phase diagram of the equilibrium point is obtained, as shown in Figure 3. When (x, y) falls in the USVW region, the system converges to the ideal state in which both the construction unit and labor company switch to industrial workers. When (x, y) falls in the USVO region, the system converges to the bad state that both sides choose to use migrant workers instead of switching to industrial workers.

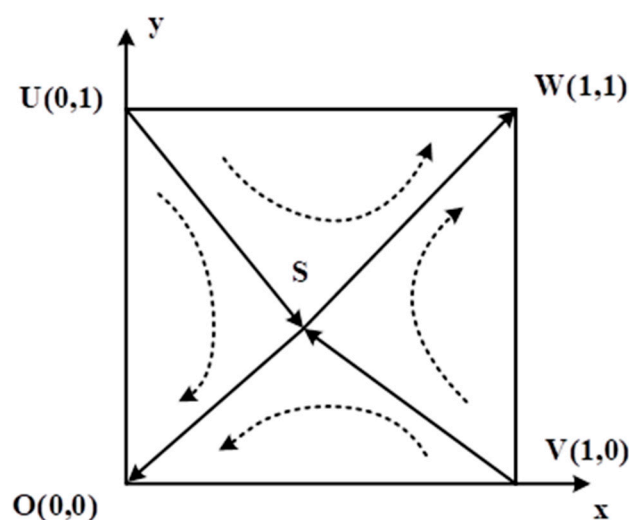


Figure 3. Phase diagram of the evolutionary game. Note: Drawing made using Microsoft Visio Professional 2016.

2.2.3. Effects of Parameter Changes

The group members involved in the game have myopic optimal response dynamics in nature. The initial state affects the behavioral patterns of the game participants in a customary manner and ultimately determines the direction in which the group equilibrium strategy moves [64]. The closer (x^*, y^*) converges to the point O, the larger the area of the quadrilateral USVW is. It indicates that the possibility of the evolutionary game converging to the ideal state W (both sides of construction unit and labor company choose to switch to industrial workers) is greater.

In general, the higher transformational return on investment (ROI), the higher R_i is and the smaller I_i is. That is, the closer (x^*, y^*) converges to the origin O, the better it is for the system to reach the ideal stable state. Therefore, the higher level of knowledge about the labor system in the construction market, the more it is conducive to the transformation revenue R_i maintained at a high level. The market tends to choose the enterprises that

switch to industrial workers (referring to construction units and labor companies). The larger scale of training and employment of transformational industrial workers, the higher degree of standardization and normalization. This is the more conducive to saving the amount of transformation investment I_i , which speeds up the convergence of evolutionary game to the ideal state. In addition, an information-based labor platform is constructed, and construction techniques for industrial workers is innovated. These measures are conducive to reducing the additional labor cost and transformation investment I_C of construction unit. As a result, the expected return of transformation investment is improved.

Under the condition of spillovers and incentives, the “free-rider” behavior is inhibited as the labor system is constructed and improved. The income spillover factors (η and θ) decrease, which drives the system to converge to the desired state at a faster rate. In addition, as the probability of regulation and incentives increase, α , β , and S_i , also improve. Accordingly, the opportunity cost of continuing to use migrant workers increase, giving both sides of the game a stronger willingness to switch to industrial workers.

3. Results

3.1. Evolutionary Game Simulation Experiments

3.1.1. Initial Numerical Simulation

In order not to lose simplicity and generality, this paper sets the construction unit's labor system transformation investment I_A to be 1. Then, the transformation ROI of construction unit is r_A , which satisfies the requirement of $R_A = (1 + r_A)I_A$. The incentive function given by relevant departments and industry associations to construction unit is R_A , which satisfies $S_A = s_A I_A$. Construction unit cedes a percentage λ of the transformation revenue to the cooperative labor company ($R_B = \lambda R_A$). Correspondingly, the labor company is also responsible for a certain percentage μ of the transformation investment ($I_B = \mu I_A$). Similarly, the transformation ROI of the labor company is given as $r_B = (1 + r_A) \times (\lambda / \mu) - 1$. The incentive function given by relevant departments and industry associations to the labor company is R_B , which satisfies $S_B = \mu s_B I_A$. Since $R_A - I_A \leq I_C$, this paper sets the additional investment $I_C = d I_A$ and $d = (1 + i)r_A, i > 0$ for the transformation. At this point, the new replicator dynamic equations $F_{An}(x)$ and $F_{Bn}(y)$ are obtained, as shown in Equations (17) and (18):

$$F_{An}(x) = x(1-x)\{(1-\eta)(1+r_A) - (1-y)d + \alpha s_A - 1\} \quad (17)$$

$$F_{Bn}(y) = y(1-y)\{x(1-\theta)(1+r_A)\lambda - \mu + \beta s_B \mu\} \quad (18)$$

The parameter settings in this paper are based on the current stage characteristics of the Chinese construction industry's labor force, as well as the definitional domain characteristics of the evolutionary game model. Under the same construction market, the parameters (e.g., transformational ROI) take the same values that have the same meanings for construction unit and labor company. According to the definitional domain characteristics of evolutionary game model, the initial values of the parameters in this paper are derived from references [29,65,66]. The set values of each parameter do not represent the actual values in the operation of the construction market. The initial values of the parameters are set as Table 3.

Table 3. Parameter's initial values and their meanings.

Name	Initial Value	Parameter Meaning	Name	Initial Value	Parameter Meaning
r_A	0.50	Transformational ROI for construction unit	α	0.50	Probability of regulation for construction unit
r_B	0.50	Transformational ROI for labor company	β	0.50	Probability of regulation for labor company
λ	0.10	Proportion of income ceded	s_A	0.25	Incentive strength for construction unit
μ	0.10	Proportion of investment sharing	s_B	0.25	Incentive strength for labor company
η	0.10	Transformation revenue spillover factor for construction unit	i	1.00	Additional investment factor for relative rates of return
θ	0.10	Transformation revenue spillover factor for labor company	d	1.00	Additional investment factor relative for relative investment

The initial values of the parameters are obtained by bringing them into the replicator dynamic equation, as shown in Equations (19) and (20):

$$F_{An}(x) = x(1-x)(y-0.525) \quad (19)$$

$$F_{Bn}(y) = y(1-y)(0.135x-0.0875) \quad (20)$$

The MATLAB platform is used for simulation. According to the above parameter settings, the saddle point of evolutionary game can be obtained, as shown in Figure 4a, which is $(x^*, y^*) = (0.652, 0.533)$. This provides a basis for setting the initial strategy selection ratio. Therefore, this paper sets $(x, y) = (0.66, 0.54)$, which is located awful close to the saddle point and more towards the desired equilibrium point W. The following simulation test results are obtained. Under the initial parameter setting conditions, when $(x, y) = (0.66, 0.54)$, the proportion of construction unit and labor company choosing to switch to industrial workers converges to 1. At this point, the system reaches the desired evolutionary stable state. In addition, construction unit reaches the desired state with a faster convergence rate compared with labor company. As shown in Figure 4b, the horizontal coordinate represents the time. Moreover, the vertical coordinate represents the proportion of the construction unit or the labor company choosing to switch to industrial workers.

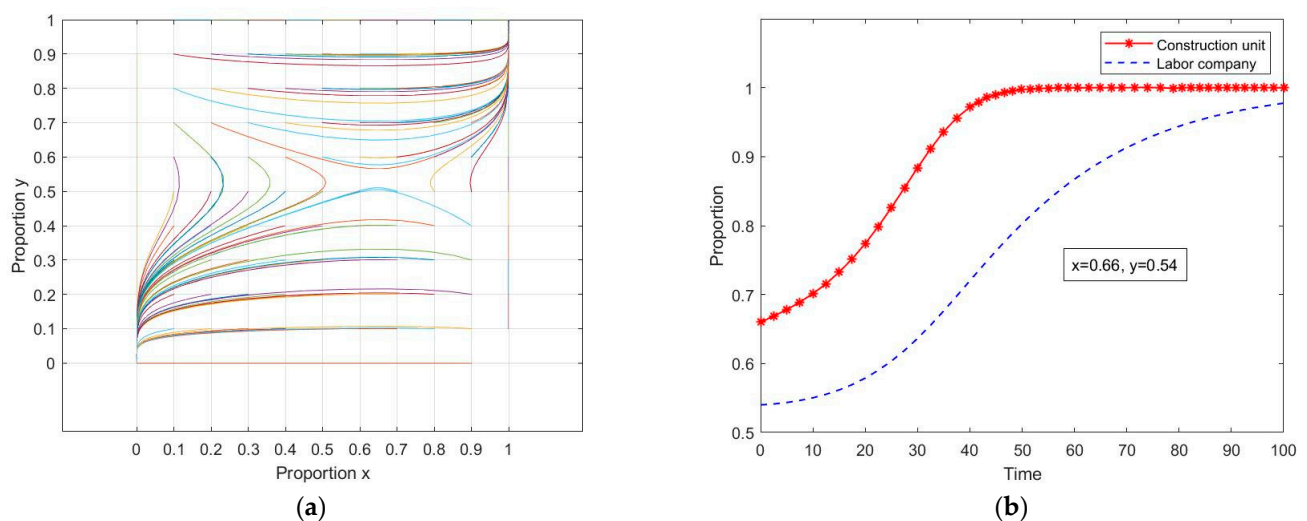


Figure 4. Initial simulation test results. (a) Phase diagram; (b) Initial simulation results. Note: Plotted with MATLAB input code.

3.1.2. Impact of Initial Scale

As shown in Figure 5a, when $(x, y) = (0.70, 0.54)$, both the construction unit and labor company converge to the desired state at a faster rate. At this point, the initial proportion of the construction unit choosing to switch to industrial workers is greater than 0.66. As shown in Figure 5b, when the initial proportion is less than 0.66, such as $(x, y) = (0.60, 0.54)$, the system converges to the undesirable state.

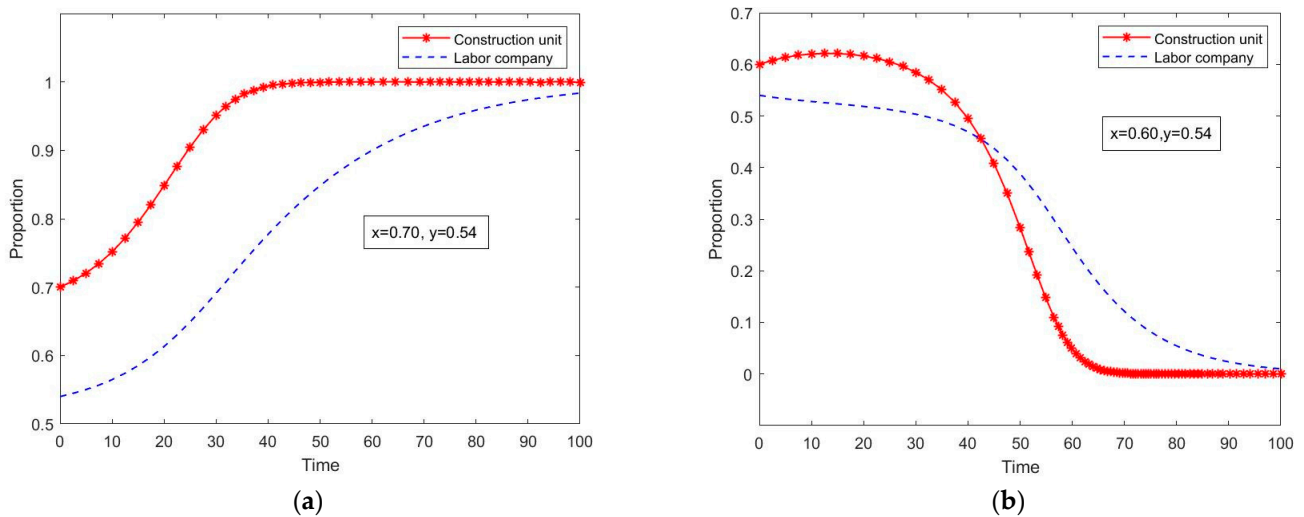


Figure 5. Test results under the change of initial proportion of the construction unit transformation. (a) Test results under $x = 0.70, y = 0.54$; (b) Test results under $x = 0.60, y = 0.54$. Note: Plotted with MATLAB input code.

As shown in Figure 6a, when $(x, y) = (0.66, 0.60)$, both the construction unit and labor company converge to the desired state at a faster rate. At this point, the initial proportion of labor companies choosing to transform industrial workers is greater than 0.54. As shown in Figure 6b, when this initial proportion is less than 0.54, such as $(x, y) = (0.66, 0.50)$, the system converges to the undesirable state.

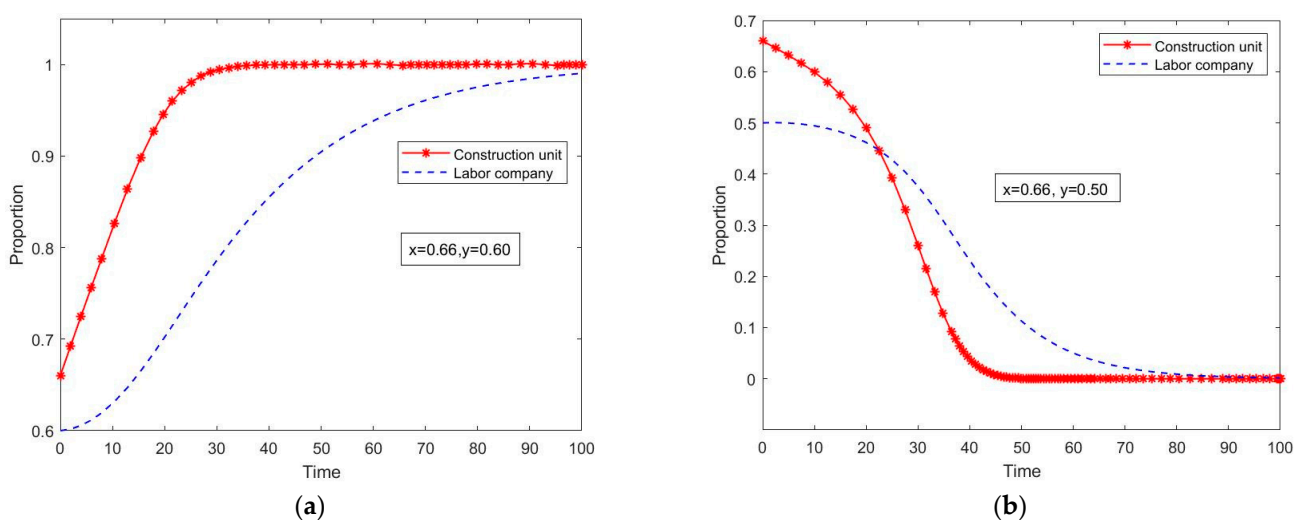


Figure 6. Test results under the change of initial proportion of the labor company transformation. (a) Test results under $x = 0.66, y = 0.60$; (b) Test results under $x = 0.66, y = 0.50$. Note: Plotted with MATLAB input code.

3.2. Sensitivity Analysis

According to the analysis of equilibrium stability points in Table 2, the values of exogenous variables determine whether the strategy portfolio is in equilibrium or not. The impact of CSI and additional investment is considered in following sensitivity analysis. When fixing the initial value of (x, y) at $(0.66, 0.54)$ and changing the settings of initial parameters $\lambda, \mu, \eta, \theta, \alpha, \beta, s_A, s_B, i$, and d , different simulation test results are obtained.

3.2.1. Impact of the Cooperation Mechanism

The proportion of income ceded and the proportion of investment sharing have a significant impact on the willingness of the labor company to switch. As shown in Figure 7a, when the proportion of income ceded is high and the proportion of investment sharing is low, such as $\lambda = 0.15$ and $\mu = 0.10$, the labor company achieves the desired steady state at a fast rate. Conversely, excessive training burdens lead to a gradual loss of willingness on the labor company to switch to industrial workers. As shown in Figure 7b, when the proportion of income ceded is low and proportion of investment sharing is high, such as $\lambda = 0.10$ and $\mu = 0.15$, the proportion of the construction unit choosing to switch to industrial workers rises and then falls sharply.

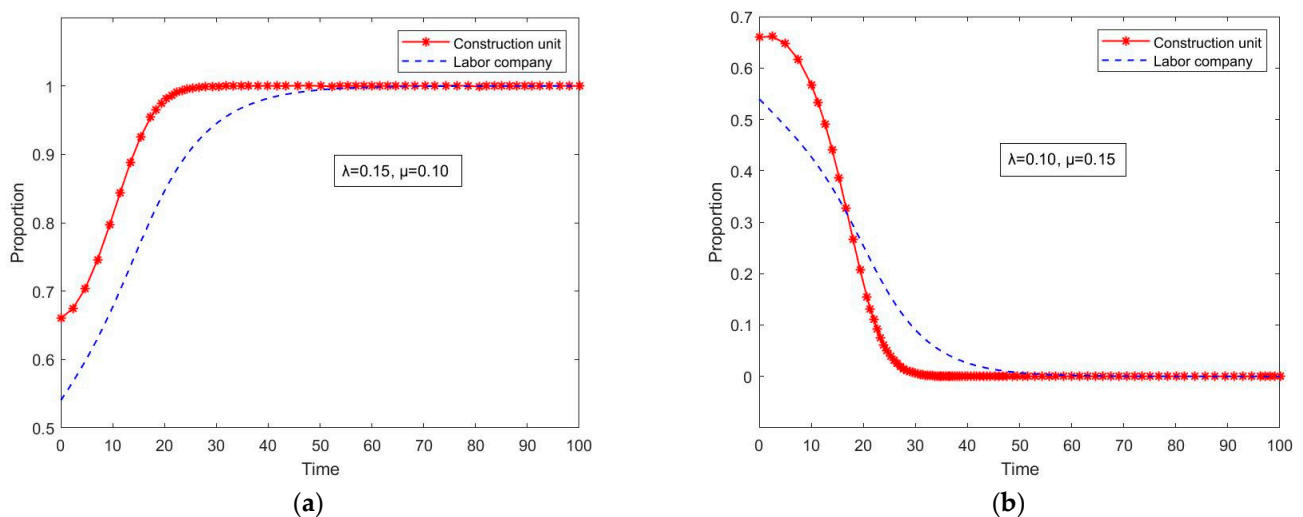


Figure 7. Simulation test results under the impact of the cooperation mechanism. (a) Test results under $\lambda = 0.15, \mu = 0.10$; (b) Test results under $\lambda = 0.10, \mu = 0.15$. Note: Plotted with MATLAB input code.

3.2.2. Impact of Spillover Effects

As shown in Figure 8a, when the spillover effect of the transformation income diminishes, such as $\eta = 0.05$ and $\theta = 0.05$, the system converges to the desired evolutionary steady state at a faster rate. Conversely, as shown in Figure 8b, when the spillover effect increases, such as $\eta = 0.15$ and $\theta = 0.15$, the system converges quickly to the undesirable state where both sides continue to use migrant workers.

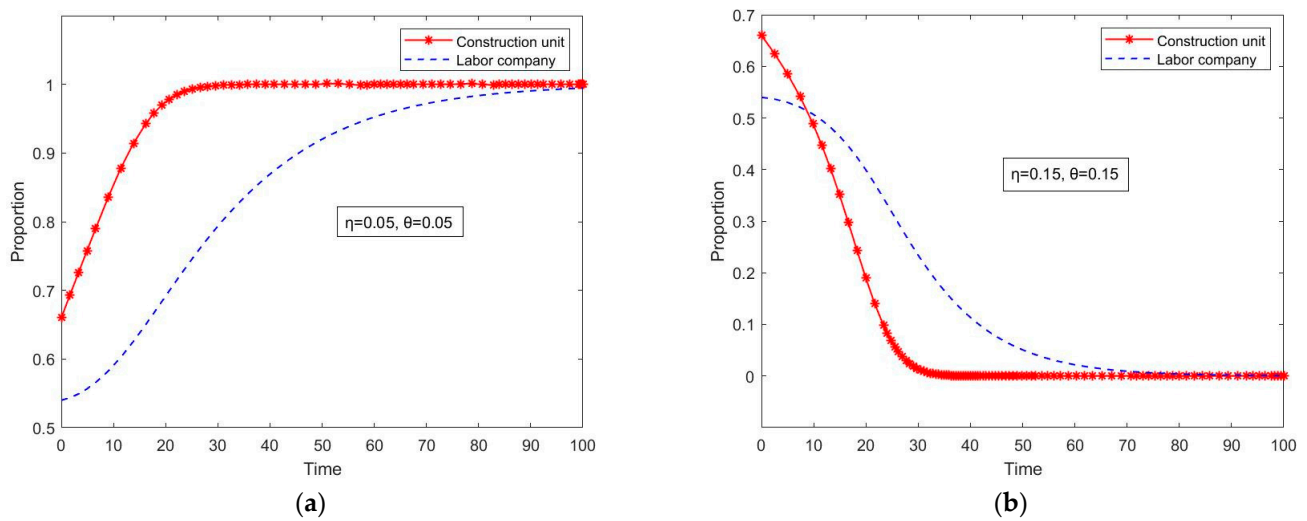


Figure 8. Simulation test results under the spillover effect. (a) Test results under $\eta = 0.05, \theta = 0.10$; (b) Test results under $\eta = 0.15, \theta = 0.15$. Note: Plotted with MATLAB input code.

3.2.3. Impact of the Incentive Mechanism

As shown in Figure 9a, when the regulatory probabilities and rewards are increased, such as $\alpha = 0.6, \beta = 0.6, s_A = 0.3$, and $s_B = 0.3$, the system converges to the desired evolutionary stable state at a faster rate. Conversely, as shown in Figure 9b, when the regulatory probabilities and rewards are weakened, such as $\alpha = 0.4, \beta = 0.4, s_A = 0.2$, and $s_B = 0.2$, the system is unable to reach desired state. Both the construction unit and labor company give up switching to using industrial workers.

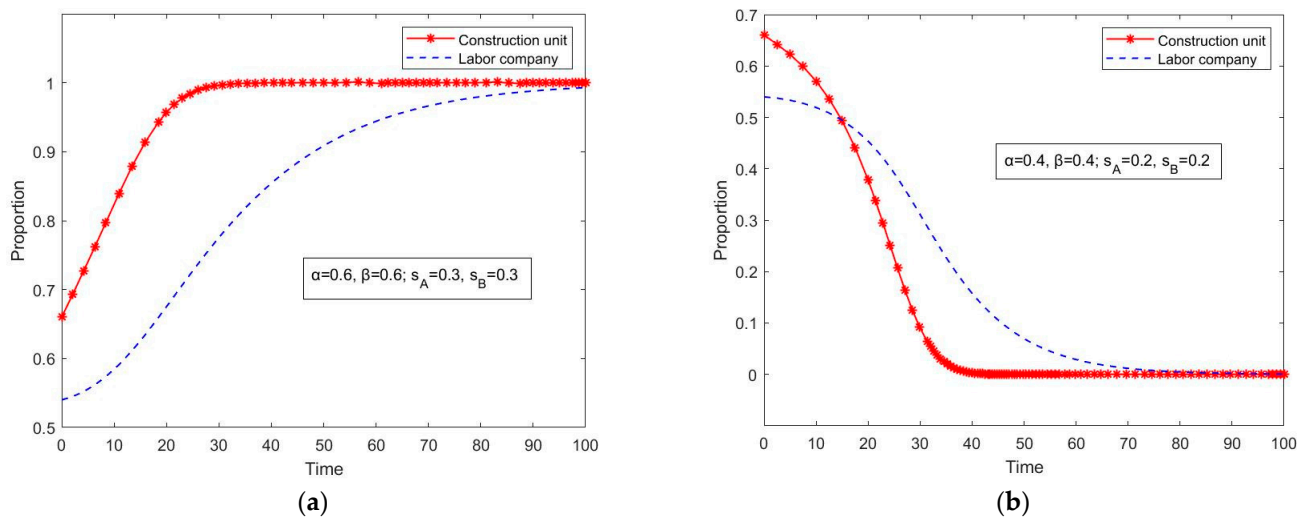


Figure 9. Simulation test results under the incentive mechanism. (a) Test results under $\alpha = 0.6, \beta = 0.6, s_A = 0.3$, and $s_B = 0.3$; (b) Test results under $\alpha = 0.4, \beta = 0.4, s_A = 0.2$, and $s_B = 0.2$. Note: Plotted with MATLAB input code.

3.2.4. Impact of Additional Investment

In particular, when the labor company chooses to continue using migrant workers while the construction unit chooses to switch, the change of additional investment I_c affects the evolutionary trend of the whole system. As shown in Figure 10a, when the additional investment coefficient of relative return i decreases, such as $i = 0.5$ and $d = 0.75$, the rate at which both sides reach the desired state will increase. Conversely, as shown in Figure 10b, when the additional investment coefficient of relative return i increases, such as $i = 1.5$

and $d = 1.25$, the construction unit voluntarily gives up switching due to the excessive additional investment.

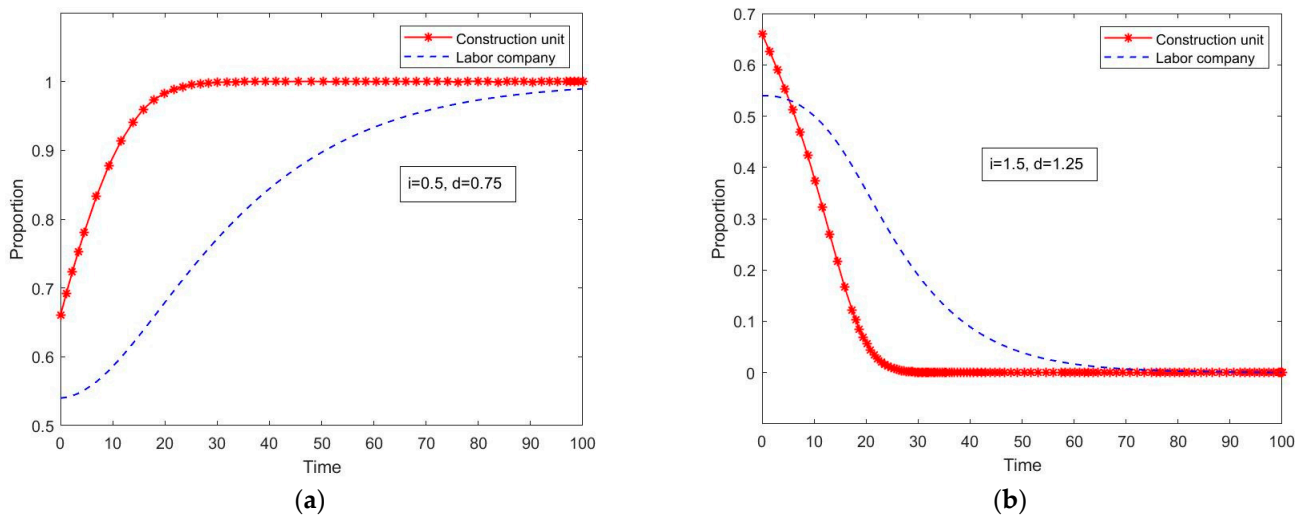


Figure 10. Simulation test results under the impact of additional investment. (a) Test results under $I = 0.5, d = 0.75$; (b) Test results under $i = 1.5, d = 1.25$. Note: Plotted with MATLAB input code.

4. Discussion and Implications

4.1. Analysis and Discussion of Results

From the simulation results in Figures 5 and 6, the initial proportion of construction unit and labor company choosing to switch has a significant impact on final stable state of the evolutionary game. Furthermore, the initial state affects the way of strategy selection of the construction unit and labor company in an inertial way. Ultimately, it determines the direction of the equilibrium strategy movement. Insufficient knowledge, motivation, and willingness of the construction unit and labor company can lead to a very low proportion of choosing to switch. Under the initial conditions, when both sides choose to switch with a low proportion, the final stable evolutionary game strategy converges to an undesirable state. At this point, the construction unit and labor company choose to continue to use the migrant workers. On the contrary, when the proportion of switching is high, the evolutionary game converges to the desired state with a fast speed. Relatedly, Liu and Ren emphasized that the workers' skills training and firms' management practices will affect the level of industrialization of construction workers [25,67].

From the simulation results in Figure 7, when the proportion of the construction unit's benefit concession increases, the labor company's transformation enthusiasm is greatly increased. Conversely, when the proportion of the labor company's investment sharing increases, its willingness to switch is reduced. The relative rate of return increases in the short term. Moreover, the proportion of the construction unit's choice of switching to industrial workers increases. However, the proportion of switching to industrial workers decreases in the long term. As a result, the system will automatically converge to an undesirable state.

From the simulation results in Figure 8, when the spillover effect decreases, the probability of both sides "reap without sowing" is reduced. At this point, the enthusiasm of switching is significant for the construction unit and labor company. When the spillover effect is more significant, the probability of both sides to "reap without sowing" increases. At this point, the willingness of the construction unit and labor company to switch decreases. Finally, the system automatically converges to an undesirable state. When hiring industrial workers, the construction unit faces great risks in their transformation investments due to the lack of a sound market mechanism on the labor market. Therefore, there is insufficient incentive to hire industrial workers, which prevents labor company from obtaining due rewards and cede benefits when training industrial workers. Evolutionary game eventually

converges to an undesirable state. This is in line with the findings of Zeng [60]. The respective industry responsibilities of the construction unit and labor company should be strengthened.

From the simulation results in Figure 9, when the relevant departments and industry associations organize stronger regulation and incentives, there are potential losses and costs. At this time, if construction unit or labor company chooses to continue to use migrant workers, they cannot get the incentives. This implies that stronger incentives and advanced regulatory measures can improve the relative expected returns of switching. Therefore, violating the requirements of the labor system faces a high opportunity cost, which pushes the evolutionary game to converge to the desired state at a fast rate. On the contrary, lower incentives and poor regulatory measures makes the gap between two decision-making benefits not obvious. This, in turn, leads to a reduced willingness of the construction unit and labor company to switch. Eventually, the system automatically converges to an undesirable state. This is similar to the findings of Han et al. Their findings mentioned that a skill-quality-oriented incentive system should be established [68].

From the simulation results in Figure 10, when investment is required to be large by the construction unit to secure the transformation, it leads to a lack of motivation. At this point, the system converges to an undesirable state. As the labor company unilaterally abandons the transformation, it is too costly for the construction unit to maintain the switching strategy. When the additional investment required by the construction unit to switch is at a lower level, its willingness to switch is significant. Finally, the system automatically converges to the desired state. Interestingly, this is different from the discussion results of Su [29]. The cost of transformation affects the final evolutionary outcome, not only the speed of evolution.

4.2. Policy Implications

1. On the basis of a sound training mechanism and employment standards, the construction unit and labor company should strengthen education on the employment system. Both sides should study in depth the government's circulars and institutional documents on the transformation of industrial workers. Corporate executives carry out the communication of the employment method and management spirit in the context of intelligent construction and refined management. Ensuring the initial enthusiasm of the construction unit and labor company for the reform of the labor system is conducive to the desired equilibrium between two sides.
2. Symbiotic cooperation between the construction unit and labor company should be strengthened. Through a fair benefit distribution and investment sharing mechanism, a benign cooperation between the two can be reached. The willingness of the labor company and construction unit to train and employ industrial workers is also upheld. An informatization platform should be established with the circulation of construction workers as a link between the construction unit and labor company. Moreover, the integrated chain for the training, hiring, management, assessment, and circulation of construction workers can effectively promote both sides to achieve the ideal balance.
3. The main role of the construction unit and labor company in the organization and skills training of construction workers should be exploited. More specifically, the vocational skills education and training system for construction workers should be established, in which the government, industry, enterprises, and universities jointly participate. Relying on large- and medium-sized projects, the actual engineering production and skills assessment should be closely linked. When both sides of decision making are involved in the transformation of the industrial workers, it becomes more difficult for them to "reap without sowing".
4. Relevant local government departments and industry associations should accelerate the transformation of functions. They should encourage reform of the labor system, strengthen incentives, and improve regulatory measures. As a result, the opportunity cost of continuing to use migrant workers by both sides increases. In concrete terms,

government departments and industry associations should conduct regular surveys to reward companies for good transformation of industrial workers. If necessary, they should criticize and penalize enterprises for undesirable employment practices. Furthermore, they should open up public mailboxes to listen to the suggestions of construction workers and the general public. Thus, the situation should be verified and dealt with in a timely manner.

5. When labor company unilaterally choose to continue to use migrant workers, measures should be taken to increase construction unit's willingness to switch. This means that the additional investment of construction unit should be effectively reduced. The effectiveness of public services in the training, hiring and distributing of construction workers should be enhanced. Through introducing targeted enterprise relief policies, the relevant government departments should strengthen precise financial support for the transformation of construction unit. Therefore, business transformation clusters are nurtured. Over the long term, they can effectively reduce the additional investment in relative returns.

In addition, a traceability system for the construction labor market should be established and improved. This is conducive to increasing construction workers' awareness and acceptance of their own skill upgrading and work pattern transformation. Government, industry, and enterprises are jointly involved in the construction of an information-based labor market circulation platform. The negative consequences of information asymmetry and labor market failures are, thus, mitigated. Ultimately, the willingness of the construction unit and labor company to switch is safeguarded.

5. Conclusions and Recommendations

5.1. Conclusions

Construction industry workers are characterized by knowledge, specialization, and technology. They are the powerful grip for the transformation of intelligent and green construction in the era of information technology. However, the employment of migrant workers in the construction industry is deeply entrenched among construction units and labor companies. The transformation to industrial workers involves a multitude of interests that need to be weighed in decision making. Taking the game relationship between the construction unit and the labor company as the research object, this study analyzes the equilibrium strategy between them. The evolutionary game model based on the CSI is developed in the process. The effect of externally relevant variables on equilibrium stability is analyzed using MATLAB simulations. Based on the results of analysis, transformational recommendations are proposed. This paper draws four main conclusions. They are of theoretical and practical significance for promoting the transformation of the employment system of the construction unit and labor company from migrant workers to industrial workers.

In the evolutionary game model, the values of the parameters of the other factors are fixed and only the values of the parameters of the object of analysis are changed. (1) The system is in a desired positive state when increasing the initial proportion of the construction unit or labor company choosing to switch. (2) The system is in a desired positive state when increasing the proportion of income ceded by the construction unit to the labor company. Conversely, the system is in an undesirable negative state when increasing the labor company's share of investment in construction unit. (3) The system is in an adverse negative state when increasing the revenue spillover factors for the transformation benefits of the construction unit and labor company. (4) The system is in a desired positive state when increasing the level of regulation and incentives from relevant government departments and industry associations.

5.2. Recommendations

The equilibrium strategy for the transformation of migrant workers to industrial workers in this study focuses on the construction unit and labor company. Although some

valuable suggested countermeasures are provided for the transformation, there are still some limitations to be noted. Firstly, the payoff function of the main body of the game is to be improved. More specifically, the scientific validity of the CSI mechanism hypothesis is to be further verified. Secondly, the main role of government departments and industry associations are not considered. Thirdly, the influence of the transformation willingness of the construction workers themselves is not considered. Finally, the transformation of industrial workers in the construction industry is also linked to the reform of the employment system in other industries (e.g., manufacturing industry). However, the article does not consider this part.

Future work could consider refining the study in the following ways. In the subject analysis, government departments and industry associations can be studied as decision-making subjects. Moreover, construction workers act as both the object and the subject of the decision. In view of this, a more complex evolutionary game analysis can be conducted. In the CSI assumptions, the role of punitive mechanism can be added. In addition to the incentive system, the relevant government departments can also take punitive measures to promote the transformation. Moreover, the impact of social labor reforms on the transformation of industrialization of construction workers can be considered. Within the whole society, the treatment of workers should be upgraded, the employment system should be improved, and the public perception of the occupation should be raised. These are potentially important ways to realize the transformation of industrial workers in the construction industry. Thus far, research around the transformation from migrant workers to industrial workers has mostly proposed cultivation and safeguard measures from a qualitative perspective. Future research should switch more to quantitative research on the internal mechanism.

Author Contributions: Conceptualization, M.G.; software, M.G.; validation, M.G. and F.G.; writing—original draft preparation, M.G., Y.L. and F.G.; writing—review and editing, M.G., J.G. and F.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the National Natural Science Foundation of China (Grant No: 71440009).

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

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