Promoting Construction Labor Professionalization: An Evolutionary Game Perspective

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Abstract: A shortage of skilled laborers has constrained the new development path called Construction 4.0, which is proposed to improve the construction industry with advanced technologies. It should be noted that the mismatch between labor skills and technological progress will harm the sustainable development of the construction sector. In China, a three-tier management structure consisting of contractors, labor subcontractors, and laborers is widespread in the labor market. Considering the relationship between laborers and construction firms, promoting construction labor professionalization depends on the cooperation of general contractors and labor subcontractors. Previous studies have focused on training techniques and methods, but have neglected to investigate whether stakeholders are willing to cooperate in training labor. Considering that the standard workforce is more likely to receive human resource investment, this paper aims to analyze the strategic choice of related stakeholders in cultivating the standard workforce. Since evolutionary game theory has proven to be an effective method to study the symbiotic evolution between stakeholders, this paper will apply it to develop an evolutionary game model and conduct analysis. Moreover, this research examines how government incentive policy affects the dynamic evolution process of cultivating a standard workforce. The results suggest that without government incentives, general contractors and labor subcontractors tend to choose a contingent workforce. When the government subsidy reaches a certain level, general contractors and labor subcontractors are willing to cooperate in cultivating a standard workforce. Additionally, it is worth noting that compensation for labor subcontractors is relatively more effective than that for general contractors in promoting construction labor professionalization. Furthermore, some suggestions and countermeasures are proposed to help to cultivate a standard workforce in China.

Keywords: construction industry; labor professionalization; general contractors; labor subcontractors; government; evolutionary game theory

1. Introduction

Technological progress is a key factor in achieving sustainable development [1]. Recently, Industry 4.0 has created new opportunities for the construction industry to implement technological upgrades, referred to as Construction 4.0 [2]. Construction 4.0 aims to improve the construction industry by utilizing advanced technologies, including Digital Twin Construction, the Internet of Things, and 3D printing [3,4]. As a labor-intensive industry, the construction sector needs to train its workforce to meet the technological advances of Construction 4.0 [5]. However, there is a widely acknowledged and enduring shortage of skilled construction laborers [6,7]. The gap between labor skills and construction technology will pose a threat to the sustainable development of the construction industry [8]. Thus, in order to ensure sustainable development, it is crucial to address the issue of the shortage of skilled laborers in the construction sector.

One effective way to resolve the shortage of skilled laborers is to promote construction labor professionalization [9]. Construction labor professionalization means that unskilled
pure manual laborers transform into skilled laborers by receiving professional training. Li et al. [10] used virtual reality to train laborers on how to inspect potential hazards on construction sites. Ahn et al. [11] applied 3D Building Information Modeling to assist in labor training. Guo et al. [12] developed a game technology-based platform for training laborers in a virtual environment. Akanmu et al. [13] established a cyber-physical postural system for training laborers on safe work postures. These scholars have proposed effective training methods that can promote labor professionalization. However, these methods may entail extra costs, which may deter stakeholders from adopting them, given the high labor costs in the construction industry [14].

Promoting labor professionalization is a complex activity that depends on the collaboration of various stakeholders, such as the government, enterprises, and associations [15]. However, some stakeholders may have conflicting interests or behaviors that hinder labor training [16]. To guide them to adopt positive strategies, it is important to analyze their choices in promoting labor professionalization. Thus, this paper uses evolutionary game theory, which is a useful tool to study stakeholder behavior in complex situations [17,18], to examine how representative stakeholders’ strategic choices affect labor training outcomes. The paper is structured as follows: The next section provides the literature review. The following section introduces the basic information of the methodology. Then, the paper analyzes how general contractors and labor subcontractors behave in promoting construction labor professionalization with or without government intervention. Next, the paper discusses the implications of the model results. Finally, the paper concludes with a summary of the main findings.

2. Literature Review

2.1. Labor Professionalization

Promoting labor professionalization is closely related to vocational education and training (VET), which is a skill-based education and training that prepares people for specific occupations. VET is essential for the training program as it equips laborers with technological knowledge and helps them cope with the changes in the labor market [19]. Evidence from some countries suggests that VET can significantly enhance the skills of local laborers.

(1) In Germany, VET is based on a dual system, which combines workplace training and college training to prepare people for specific occupations [15]. VET follows a national unified standard and is coordinated by the Federal Ministry of Education and Research [20]. The firms provide and fund workplace-based training, while the vocational schools are supported by the government [21]. Upon completion of the VET program, trainees will receive a vocational qualification that is valued in the labor market.

(2) In Denmark, the overall framework of VET is formulated by the Ministry of Education [22]. The trade committees develop training regulations for different occupations and ensure that the trainees receive systematic training [20]. VET is funded by both the government and the employers: the government supports school-based training, while the employers pay wages to apprentices [22]. Trainees who pass the final assessment, which is conducted by a panel of employer, labor, and teacher representatives, earn a vocational qualification [22].

(3) In Australia, the government establishes the framework of VET, which includes the Australian Qualifications Framework and Training Packages [23]. Technical and Further Education (TAFE) institutes and other registered training organizations (RTOs) deliver customized training programs based on this framework [24]. Employers must provide apprentices with both on-the-job and off-the-job training at a TAFE institute or an RTO for a specified duration. Apprentices who complete the training successfully receive a nationally recognized qualification [25].

Unlike the above countries where official institutions, employer associations, and trade unions collaborate to support VET, in China, VET is managed by two ministries: the
Ministry of Education (MOE) and the Ministry of Human Resources and Social Security (MOHRSS) [22]. The MOE-dominated vocational schools offer both general and vocational education to students. The MOHRSS-managed technical schools focus on vocational training. Additionally, skilled laborers’ schools, training centers, and industry associations will provide vocational skills training to laborers [26]. The government sets the direction of VET development by making policies [27]. The social partners mainly adjust to the government’s framework as a supplement to policy implementation [28]. Although the government’s support for relevant schools and institutions has some positive outcomes, it should be noted that most migrant laborers do not have access to receive vocational training in these places. Therefore, workplace training provided by general contractors has become a vital way to improve laborers’ skills. However, in practice, workplace training faces some challenges, such as low participation of relevant firms [29], and insufficient willingness of labors to participate [16], which lead to disappointing results. Hence, more measures are needed to encourage construction firms to participate in enhancing construction labors’ professionalization in the future.

2.2. Stakeholders in Promoting Labor Professionalization

Generally, there are two types of labor: “standard” and “contingent” [30]. The main differences between them are the length of their employment relationship and the amount of human resources (HR) investment they receive from the firm [31]. Standard laborers have ongoing employment relationships and receive more HR investments, while contingent ones have temporary employment relationships and receive fewer HR investments [29]. Thus, compared to contingent laborers, standard laborers have more chances to receive HR investments to participate in vocational training. Hence, cultivating standard labor is necessary to promote construction labor professionalization. In China, a common management structure in the construction sector is contractor-labor subcontractor-labor [32], as shown in Figure 1. The structure indicates that the majority of laborers are employed by labor subcontractors. The construction contractors employ laborers from labor subcontractors to complete construction operations according to the need of construction projects. This kind of pay-as-you-go rule provides contingent labor services for contractors [33].

![Figure 1. The three-tier management structure.](image)

Considering the impact of the government, the main participants in cultivating a standard workforce are general contractors, labor subcontractors, and the government. Their behavior is crucial to promote construction labor professionalization. Therefore, it is meaningful to analyze how to guide the three stakeholders to participate in cultivating a standard workforce. Otherwise, although training methods have been developed to improve the skill level of construction laborers, it will be difficult to achieve the target of promoting construction labor professionalization without the three stakeholders’ participation.
2.3. Game Model Applications

The complexity of economic activity leads to a gap between the computational capacity of an agent and the complexity of its environment [34]. This makes it hard and time-consuming to obtain relevant information, which may not even be useful. Under uncertainty, agents struggle to evaluate the benefits of future actions. Thus, in real economic activities, agents cannot be fully rational [35].

The assumption of “perfect rationality” in classical game theory differs from that of “limited rationality” in evolutionary game theory [36]. The latter assumption is more suitable for predicting the behavior of game participants in a dynamic system where behavior changes over time [37]. Evolutionary game theory applies game theory to evolving populations in biology [38]. It simulates a community of players with different strategies and their evolution using natural selection methods instead of analyzing the game’s properties directly [39]. Two essential and elementary concepts have laid a solid foundation for the development of evolutionary game theory: replicator dynamics [40] and evolutionarily stable strategy (ESS) [41], which loosens the assumption of complete rationality and emphasizes bounded rationality and dynamic equilibrium [42].

External and internal factors make it hard for the government or firms to act rationally in real economic activity [43]. The stakeholders will observe, imitate, and learn from each other when making decisions [36]. Thus, it is necessary to equip to reflect this dynamic process. Given this, the authors use evolutionary game theory to study the strategies of general contractors, labor subcontractors, and the government in cultivating a standard workforce. Two key questions will be answered: First, how do general contractors and labor subcontractors evolve their behavior? Second, how do government incentives affect their strategy?

3. Methodology

To investigate the viewpoints on the construction labor market, questionnaires were distributed to the related practitioners. A total of 60 questionnaires were randomly distributed, while 53 questionnaires were received, 7 were not returned, yielding an 88.3% response rate. As shown in Table 1, the respondents consisted of 25 general contractors, 21 labor subcontractors, and 7 researchers.

Table 1. Basic information of interviewees.

<table>
<thead>
<tr>
<th>Category</th>
<th>Frequency</th>
<th>Dist.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>35</td>
<td></td>
<td>66.0</td>
</tr>
<tr>
<td>Female</td>
<td>18</td>
<td></td>
<td>34.0</td>
</tr>
<tr>
<td>Qualification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Master degree</td>
<td>16</td>
<td></td>
<td>30.2</td>
</tr>
<tr>
<td>Bachelor degree</td>
<td>31</td>
<td></td>
<td>58.5</td>
</tr>
<tr>
<td>Other</td>
<td>6</td>
<td></td>
<td>11.3</td>
</tr>
<tr>
<td>Years of experience</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 5</td>
<td>13</td>
<td></td>
<td>24.5</td>
</tr>
<tr>
<td>5–10</td>
<td>20</td>
<td></td>
<td>37.7</td>
</tr>
<tr>
<td>10–15</td>
<td>14</td>
<td></td>
<td>26.4</td>
</tr>
<tr>
<td>More than 15</td>
<td>6</td>
<td></td>
<td>11.3</td>
</tr>
<tr>
<td>Respondent type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General contractors</td>
<td>25</td>
<td></td>
<td>47.2</td>
</tr>
<tr>
<td>Labor subcontractors</td>
<td>21</td>
<td></td>
<td>39.6</td>
</tr>
<tr>
<td>Researcher</td>
<td>7</td>
<td></td>
<td>13.2</td>
</tr>
</tbody>
</table>

Table 2 shows that most respondents think that the current labor market lacks skilled laborers. Moreover, this shortage will harm the construction industry’s growth. To address this issue, 88.6% of respondents support the idea that cultivating a standard workforce can improve laborers’ skills. However, the high cost and high turnover of construction
laborers prevent it. Furthermore, to overcome this challenge, 73.6% of respondents think that government incentives are crucial for cultivating a standard workforce. Based on the result of the questionnaires, the following conclusions can be drawn:

- For general contractors, two kinds of employment modes create different benefits. Employing contingent laborers from the labor subcontractors, it has some advantages, such as easy adjustment of staffing levels, reducing the fixed cost, and avoiding the risk of staff turnover [44]. On the contrary, employing a standard workforce has the advantages of improving the quality of products [45], easing the industry turnover rate [46], and alleviating skill shortages [46]. However, employing standard labor has three common challenges: (1) the cost of investment for a standard workforce [47,48]; (2) the risk of losing a standard workforce [49]; (3) the uncertainty of future projects [50].

- In the three-tier management structure, a labor subcontractor usually provides construction labor for contractors. For labor subcontractors, investing in laborers will enhance competitiveness in the labor market. However, due to its limited economic strength [51], labor subcontractors will take a lot of risks in the cultivation standard workforce. including (1) unclear requirements for laborers in the labor market [51]; (2) the poor ability to resist cost risks [51]; (3) the risk of labor turnover [52].

- Government policies are likely to exert a significant impact on the labor market of the construction industry [27]. As a result, the strategic choices of both general contractors and labor subcontractors will be influenced. Hence, it is imperative that the government exercise caution when promulgating policies. The government should also take into account certain issues: (1) how to guide related companies to cultivate a standard workforce; (2) how to ensure the effectiveness of the policy; (3) how to reduce the government’s financial burden.

### Table 2. Viewpoints of construction labor market.

<table>
<thead>
<tr>
<th></th>
<th>Totally Agree (%)</th>
<th>Agree (%)</th>
<th>Not Sure (%)</th>
<th>Disagree (%)</th>
<th>Absolutely Disagree (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is difficult to recruit skilled labors in the construction industry.</td>
<td>52.8</td>
<td>34.0</td>
<td>13.2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>There is an issue of project risk led by contingent labors.</td>
<td>43.4</td>
<td>34.0</td>
<td>15.0</td>
<td>7.6</td>
<td>0</td>
</tr>
<tr>
<td>Lack of skilled labors will constrain the development of construction industry.</td>
<td>43.4</td>
<td>28.3</td>
<td>18.9</td>
<td>5.7</td>
<td>3.8</td>
</tr>
<tr>
<td>General contractors are more willing to hire workforce who have relevant experience.</td>
<td>41.5</td>
<td>35.9</td>
<td>17.0</td>
<td>5.7</td>
<td>0</td>
</tr>
<tr>
<td>Cultivating standard workforce can promote skill level of labors.</td>
<td>43.4</td>
<td>45.2</td>
<td>11.3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>High cost hinders to cultivate standard workforce.</td>
<td>68.0</td>
<td>18.9</td>
<td>13.2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>High mobility of construction labors hinders the cultivation of standard workforce.</td>
<td>43.4</td>
<td>37.7</td>
<td>15.1</td>
<td>3.8</td>
<td>0</td>
</tr>
<tr>
<td>Government incentive will enhance the willingness of companies to cultivate standard workforce.</td>
<td>35.9</td>
<td>37.7</td>
<td>22.6</td>
<td>1.9</td>
<td>1.9</td>
</tr>
</tbody>
</table>

To further study the behavior of the stakeholders in cultivating a standard workforce, the authors developed an evolutionary game model to analyze the strategy of general contractors and labor subcontractors, with or without government incentive. Considering the three-tier management structure in the labor market, general contractors have two pure strategies: (1) establishing long-term cooperation with labor subcontractors in cultivating a standard workforce; (2) employing contingent laborers, referred to as “cooperation” and “not cooperation”. Labor subcontractors also have two pure strategies, whether to cultivate a standard workforce or not, referred to as “cultivating” and “not cultivating”. Since the
revenue of general contractors and labor subcontractors is partly dependent on the choice of the other; they both take the risk of loss due to the other’s choice.

Accordingly, five assumptions are presented for the above strategies:

**Assumption 1.** General contractors and labor subcontractors are willing to cooperate in cultivating a standard workforce. In this situation, general contractors’ revenue is $R_p$, the cost is $C_p$. Besides, general contractors will provide certain funds $C_f$ to labor subcontractors in cultivating a standard workforce. Relatively, labor subcontractors’ revenue is $R_s$ and the cost is $C_s$, which is the extra cultivating cost.

**Assumption 2.** General contractors intend to establish a long-term cooperation mechanism to cultivate a standard workforce with labor subcontractors, while labor subcontractors are unwilling to cultivate a standard workforce. In this situation, general contractors’ revenue is $R_n$. Assume that $R_n < R_p$, namely, lack of cooperation with labor subcontractors is ineffective to cultivate a standard workforce. What’s more, general contractors will cost $C_p$ and bear the loss of $C_f$ to assist labor subcontractors in cultivating a standard workforce. Relatively, labor subcontractors’ revenue is $R_s$ and the cost is $C_o$, which is the penalty of not cultivating.

**Assumption 3.** General contractors intend to employ contingent laborers, while labor subcontractors decide to cultivate a standard workforce. In this situation, due to the lack of financial support from general contractors, the results achieved by labor subcontractors in cultivating a standard workforce are limited. General contractors’ revenue is $R_q$ ($R_n < R_q < R_p$), and the cost is $C_n$ ($C_n < C_p$). Relatively, labor subcontractors’ revenue is $R_o$ ($R_o < R_s$) and the cost is $C_s$.

**Assumption 4.** General contractors and labor subcontractors are unwilling to participate in cultivating a standard workforce. General contractors’ revenue is $R_n$, and the cost is $C_n$. Relatively, labor subcontractors’ revenue is $R_o$ and the cost is $0$.

Theoretically, revenue and cost are related to the changeable market. This study concerns how to motivate relative firms to cultivate a standard workforce. Therefore, to simplify and refine the model, this study assumes that the revenue and costs of general contractors and labor subcontractors stay the same.

**Assumption 5.** The probability that general contractors choose the strategy “cooperation” is $x$, and the probability of the strategy “not cooperation” is $1-x$, where $x$ satisfies the condition of $0 \leq x \leq 1$. The probability that labor subcontractors cultivate a standard workforce is $y$, and the probability of not cultivating is $1-y$, where $y$ satisfies the condition of $0 \leq y \leq 1$.

Based on the above assumptions, the payoff matrix can be determined without government incentives in the evolutionary game between general contractors and labor subcontractors, as shown in Table 3.

<table>
<thead>
<tr>
<th>General Contractors</th>
<th>Labor Subcontractors</th>
<th>Cultivating</th>
<th>Not Cultivating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>$R_p - C_p - C_f$</td>
<td>$R_n - C_p - C_f$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$R_s - C_s$</td>
<td>$R_n - C_o$</td>
<td></td>
</tr>
<tr>
<td>Not cooperation</td>
<td>$R_q - C_n, R_o - C_s$</td>
<td>$R_n - C_n, R_o$</td>
<td></td>
</tr>
</tbody>
</table>

When general contractors and labor subcontractors choose the strategy (cooperation, cultivating), general contractors can obtain $R_p - C_p - C_f$, and labor subcontractors can obtain $R_s - C_s$; When general contractors and labor subcontractors choose the strategy (cooperation, not cultivating), general contractors can obtain $R_n - C_p - C_f$, and labor subcontractors can obtain $R_n - C_o$; When general contractors and labor subcontractors choose the strategy (not cooperation, cultivating), general contractors can obtain $R_q - C_n$, and
labor subcontractors can obtain $R_0 - C_s$; When general contractors and labor subcontractors choose the strategy (not cooperation, not cultivating), general contractors can obtain $R_n - C_n$, and labor subcontractors can obtain $R_o$.

Setting $U_{psw}$ to be general contractors’ expected revenue on strategy “cooperation”; the expected revenue on strategy “not cooperation” is $U_{psn}$; and the average expected revenue of the general contractors is $\overline{U}_p$. Thus, the equations can be obtained to calculate each, as follows:

$$
U_{psw} = y(R_p - C_p - C_f) + (1 - y)(R_n - C_f + y(R_p - R_n)) \tag{1}
$$

$$
U_{psn} = y(R_q - C_n) + (1 - y)(R_n - C_n) = y(R_q - R_n) + R_n - C_n \tag{2}
$$

$$
\overline{U}_p = xU_{psw} + (1 - x)U_{psn} = y[(1 - x)R_q + xR_p - R_n] + x\left(C_n - C_p - C_f\right) + R_n - C_n \tag{3}
$$

Then, setting $U_{sw}$ to be the labor subcontractors’ expected revenue on cultivating the workforce; the expected revenue of labor subcontractors on not cultivating the workforce is $U_{sn}$; and the average expected revenue of labor subcontractors is $\overline{U}_s$. Thus, the equations can be obtained to calculate each, as follows:

$$
U_{sw} = x(R_s - C_s) + (1 - x)(R_o - C_s) = R_o - C_s + x(R_s - R_o) \tag{4}
$$

$$
U_{sn} = x(R_s - C_o) + (1 - x)R_n = R_o + x(R_s - C_o - R_o) \tag{5}
$$

$$
\overline{U}_s = yU_{sw} + (1 - y)U_{sn} = xyC_o - yC_o + x(R_s - C_o - R_o) + R_o \tag{6}
$$

4. Results

4.1. Analysis of Evolutionary Game Model without Government Incentives

Based on the replicator dynamic equations, the “cooperation” strategy selected by general contractors $F(x)$ and the “cultivating” strategy selected by labor subcontractors $F(y)$ is as follows:

$$
F(x) = \frac{dx}{dt} = x(\overline{U}_{psw} - \overline{U}_p) = x(1 - x)\left[C_n - C_p - C_f + y(R_p - R_q)\right] \tag{7}
$$

$$
F(y) = \frac{dy}{dt} = y(\overline{U}_{sw} - \overline{U}_s) = y(1 - y)(xC_o - C_s) \tag{8}
$$

From Equations (7) and (8), set $F(x) = 0$, and $F(y) = 0$. $(0,0), (0,1), (1,0), \text{and } (1,1)$ can be obtained as equilibrium points. When $R_p - R_q > C_p + C_f - C_n > 0$, and $C_s < C_o$ hold, the formula $F(x^*) = 0$ and $F(y^*) = 0$ can be obtained, at the same time $0 < x^* < 1$, and $0 < y^* < 1$, in which $x^* = \frac{C_s}{C_o}$, $y^* = \frac{C_p + C_f - C_o}{R_p - R_q}$, so $(x^*,y^*)$ is also an equilibrium point.

By calculating the determinant $det(J) = a_11a_{22} - a_{12}a_{21}$ and trace $tr(J) = a_{11} + a_{22}$ of the Jacobian matrix, the above equilibrium points can be judged. If $det(J) > 0$ and $tr(J) < 0$, the equilibrium point is ESS. If $det(J) > 0$ and $tr(J) > 0$, the equilibrium point is unstable. Or else, the equilibrium point is the saddle point [53].

The Jacobian matrix of the replicator dynamic equations is as follows:

$$
J = \begin{bmatrix}
(1 - 2x)\left[C_n - C_p - C_f + y(R_p - R_q)\right] & x(1 - x)(R_p - R_q) \\
y(1 - y)C_o & (1 - 2y)(xC_o - C_s)
\end{bmatrix} \tag{9}
$$

Substitute the above five equilibrium points into Equation (9), their $det(J)$ and $tr(J)$ can be obtained, as shown in Table 4.
According to the values of $C_n - C_p - C_f + R_p - R_q$, and $C_o - C_s$, the dynamic relationship and stability of replication between the two participants of the game under different conditions can be drawn, as shown in Figure 2. Moreover, ESS under different conditions can be obtained.

![Figure 2. The dynamic evolution process in cases 1–4: (a) $C_n - C_p - C_f + R_p - R_q < 0$ and $C_o - C_s < 0$; (b) $C_n - C_p - C_f + R_p - R_q < 0$ and $C_o - C_s > 0$; (c) $C_n - C_p - C_f + R_p - R_q > 0$ and $C_o - C_s < 0$; (d) $C_n - C_p - C_f + R_p - R_q > 0$ and $C_o - C_s > 0$.](image-url)

**Table 4.** The $det(J)$ and $tr(J)$ of the five equilibrium points without government incentives.

<table>
<thead>
<tr>
<th>Equilibrium Point</th>
<th>$Det(J)$</th>
<th>$Tr(J)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_1(0,0)$</td>
<td>$-(C_n - C_p - C_f) C_s$</td>
<td>$C_n - C_p - C_f - C_s$</td>
</tr>
<tr>
<td>$E_2(0,1)$</td>
<td>$(C_n - C_p - C_f + R_p - R_q) C_s$</td>
<td>$C_n - C_p - C_f + R_p - R_q + C_s$</td>
</tr>
<tr>
<td>$E_3(1,0)$</td>
<td>$-(C_n - C_p - C_f)(C_o - C_s)$</td>
<td>$C_p + C_f - C_n + C_o - C_s$</td>
</tr>
<tr>
<td>$E_4(1,1)$</td>
<td>$(C_n - C_p - C_f + R_p - R_q)(C_o - C_s)$</td>
<td>$C_p + C_f - C_n - R_p + R_q - C_o + C_s$</td>
</tr>
<tr>
<td>$E_5(x^<em>, y^</em>)$</td>
<td>$\frac{(C_n - C_p - C_f + R_p - R_q)(C_o - C_s)(C_o - C_s)}{C_o - R_p}$</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 5.** Local stability analyses of equilibrium points in case 1.

<table>
<thead>
<tr>
<th>Equilibrium Point</th>
<th>$Det(J)$</th>
<th>$Tr(J)$</th>
<th>Local Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_1(0,0)$</td>
<td>$+$</td>
<td>$-$</td>
<td>ESS</td>
</tr>
<tr>
<td>$E_2(0,1)$</td>
<td>$-$</td>
<td>$*$</td>
<td>Saddle point</td>
</tr>
<tr>
<td>$E_3(1,0)$</td>
<td>$-$</td>
<td>$*$</td>
<td>Saddle point</td>
</tr>
<tr>
<td>$E_4(1,1)$</td>
<td>$+$</td>
<td>$+$</td>
<td>Unstable point</td>
</tr>
</tbody>
</table>

Note: The ‘*’ indicates that the value is positive. ‘*’ indicates that the value is negative. ‘+’ indicates that the value is positive or negative.
Case 2: If \( C_n - C_p - C_f + R_p - R_q < 0 \) and \( C_o - C_s > 0 \)

In this case, it means that the “cooperation” strategy of general contractors cannot obtain more benefit than the “not cooperation” strategy. Relatively, labor subcontractors can obtain more benefits from the “cultivating” strategy. However, due to the lack of general contractors’ support, the equilibrium point \((0,0)\) is ESS. General contractors intend to employ contingent laborers, and labor subcontractors are reluctant to cultivate a standard workforce. Table 6 represents the local stability analyses of these equilibrium points in case 2. The duplicated dynamic trend is depicted in Figure 2b.

<table>
<thead>
<tr>
<th>Equilibrium Point</th>
<th>( Det(f) )</th>
<th>( Tr(f) )</th>
<th>Local Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_1(0,0) )</td>
<td>+</td>
<td>–</td>
<td>ESS</td>
</tr>
<tr>
<td>( E_2(0,1) )</td>
<td>–</td>
<td>*</td>
<td>Saddle point</td>
</tr>
<tr>
<td>( E_3(1,0) )</td>
<td>+</td>
<td>+</td>
<td>Unstable point</td>
</tr>
<tr>
<td>( E_4(1,1) )</td>
<td>–</td>
<td>*</td>
<td>Saddle point</td>
</tr>
</tbody>
</table>

Note: The “+” indicates that the value is positive. “−” indicates that the value is negative. “*” indicates that the value is positive or negative.

Case 3: If \( C_n - C_p - C_f + R_p - R_q > 0 \) and \( C_o - C_s < 0 \)

In this situation, general contractors will obtain more benefits from the strategy of “cooperation”. Otherwise, the choice of “not cultivating” can bring more revenue to labor subcontractors. Thus, the game will gradually converge to the equilibrium point \((0,0)\). The local stability analyses of these equilibrium points are presented in Table 7. The duplicated dynamic trend is illustrated in Figure 2c.

<table>
<thead>
<tr>
<th>Equilibrium Point</th>
<th>( Det(f) )</th>
<th>( Tr(f) )</th>
<th>Local Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_1(0,0) )</td>
<td>+</td>
<td>–</td>
<td>ESS</td>
</tr>
<tr>
<td>( E_2(0,1) )</td>
<td>+</td>
<td>+</td>
<td>Unstable point</td>
</tr>
<tr>
<td>( E_3(1,0) )</td>
<td>–</td>
<td>*</td>
<td>Saddle point</td>
</tr>
<tr>
<td>( E_4(1,1) )</td>
<td>–</td>
<td>*</td>
<td>Saddle point</td>
</tr>
</tbody>
</table>

Note: The “+” indicates that the value is positive. “−” indicates that the value is negative. “*” indicates that the value is positive or negative.

Case 4: If \( C_n - C_p - C_f + R_p - R_q > 0 \) and \( C_o - C_s > 0 \)

In this case, equilibrium points \((0,0)\) and \((1,1)\) are the ESSes. It means that the two populations will make a choice between (not cooperation, not cultivating) and (cooperation, cultivating). Table 8 presents the local stability analyses of these equilibrium points in case 8. The duplicated dynamic trend is depicted in Figure 2d.

<table>
<thead>
<tr>
<th>Equilibrium Point</th>
<th>( Det(f) )</th>
<th>( Tr(f) )</th>
<th>Local Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_1(0,0) )</td>
<td>+</td>
<td>–</td>
<td>ESS</td>
</tr>
<tr>
<td>( E_2(0,1) )</td>
<td>+</td>
<td>+</td>
<td>Unstable point</td>
</tr>
<tr>
<td>( E_3(1,0) )</td>
<td>–</td>
<td>*</td>
<td>Unstable point</td>
</tr>
<tr>
<td>( E_4(1,1) )</td>
<td>+</td>
<td>–</td>
<td>ESS</td>
</tr>
<tr>
<td>( E_5(x^<em>, y^</em>) )</td>
<td>+</td>
<td>0</td>
<td>Unstable point</td>
</tr>
</tbody>
</table>

Note: The “+” indicates that the value is positive. “−” indicates that the value is negative. “*” indicates that the value is positive or negative.

Based on the result, it shows that (not cooperation, not cultivating) is the main choice of the two participants in the construction labor market. Thus, the analysis results are consistent with the current situation in China.
In case 4, the probability of (cooperation, cultivating) being the ESS equals
\[ P = 1 - \frac{1}{2} \left( \frac{C_o + (C_f + C_p - C_g)}{R_p - R_q} \right). \]

From the equation, it can be observed that increasing the punishment cost \( C_o \) and the benefit of employing a standard workforce \( R_p \), or decreasing the cultivating cost \( C_f \) and \( C_p \), will increase the growth probability of (cooperation, cultivating). Therefore, the government can promote the cultivation of a standard workforce by taking relevant measures, such as regulating the labor market to increase the cost of punishment \( C_o \), improving the supervision of the quality of engineering projects to increase income by employing a standard workforce \( R_p \) and subside relative firms to decrease the cultivating cost \( C_f \) and \( C_p \). Besides, the lack of direct government subsidies to the companies has made it difficult to increase the enthusiasm of both parties [54]. The impact of government incentives is analyzed in the next section.

### 4.2. Evolutionary Game Model with Government Incentives

The government plays an important role in the construction skill-formation system [19]. In this section, the authors analyze the effect of government incentives on the evolutionary processes. Based on the basic model, another assumption is presented.

**Assumption 6.** The government encourages relative firms to cultivate a standard workforce by providing subsidies. General contractors who employ a standard workforce will receive compensation \( R_q \) from the government. Besides, if labor subcontractors cultivate the workforce, some of this cost will be compensated by the government, assuming the compensation is \( R_i \).

Then, according to assumptions 1–6 above, the payoff matrix of the evolutionary game between general contractors and labor subcontractors, with government incentives can be obtained, as presented in Table 9.

**Table 9.** The payoff matrix with government incentives.

<table>
<thead>
<tr>
<th>General Contractors</th>
<th>Labor Subcontractors</th>
<th>Cultivating</th>
<th>Not Cultivating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>( R_p - C_p - C_f + R_g ), ( R_s - C_o + R_l )</td>
<td>( R_n - C_p - C_f + R_g ), ( R_s - C_o )</td>
<td></td>
</tr>
<tr>
<td>Not cooperation</td>
<td>( R_q - C_o, R_o - C_s + R_l )</td>
<td>( R_n - C_o, R_o )</td>
<td></td>
</tr>
</tbody>
</table>

When general contractors and labor subcontractors choose the strategy (cooperation, cultivating), general contractors can obtain \( R_p - C_p - C_f + R_g \), and labor subcontractors can obtain \( R_s - C_o + R_l \); When general contractors and labor subcontractors choose the strategy (cooperation, not cultivating), general contractors can obtain \( R_n - C_p - C_f + R_g \), and labor subcontractors can obtain \( R_s - C_o \); When general contractors and labor subcontractors choose the strategy (not cooperation, cultivating), general contractors can obtain \( R_q - C_o \), and labor subcontractors can obtain \( R_o - C_s + R_l \); When general contractors and labor subcontractors choose the strategy (not cooperation, not cultivating), general contractors can obtain \( R_n - C_o \), and labor subcontractors can obtain \( R_o \).

The replicator dynamic equations of standard strategy selected by general contractors \( \mathcal{T}(x) \) and training strategy selected by labor subcontractors \( \mathcal{T}(y) \) are as follows:

\[
\mathcal{T}(x) = x(1-x)\left[ C_n - C_p - C_f + R_g + y(R_p - R_q) \right] \tag{10}
\]

\[
\mathcal{T}(y) = y(1-y)(xC_o - C_s + R_l) \tag{11}
\]

From Equations (10) and (11), set \( \mathcal{T}(x) = 0 \), and \( \mathcal{T}(y) = 0 \), \((0,0), (0,1), (1,0), \text{ and } (1,1)\) can be obtained as equilibrium points. When \( C_p + C_f - C_n - R_p + R_q < R_g < C_p + C_f - C_n \) and \( C_s - C_o < R_l < C_h \) hold, the formula \( \mathcal{T}(x^*) = 0 \) and \( \mathcal{T}(y^*) = 0 \) can be obtained, at the same time, \( 0 < x^* < 1, \text{ and } 0 < y^* < 1 \), where \( x^* = \frac{C_o - R_l}{C_o} \), \( y^* = \frac{C_p + C_f - C_o - R_q}{R_p - R_q} \), so \((x^*, y^*)\) is...
also an equilibrium point. The same as the basic model, the Jacobian matrix of replicator dynamic equations can be calculated, as follows:

\[
J = \begin{bmatrix}
(1 - 2x) \left[ C_p - C_f + R_q + y(R_p - R_q) \right] & x(1 - x)(R_p - R_q) \\
y(1 - y)C_o & (1 - 2y)(xC_o - C_s + R_l)
\end{bmatrix}
\]

(12)

Substituting the above five equilibrium points into Equation (12), \( \text{det}(f) \), and \( \text{tr}(f) \) can be calculated, as shown in Table 10.

<table>
<thead>
<tr>
<th>Equilibrium Point</th>
<th>( \text{det}(f) )</th>
<th>( \text{tr}(f) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_1(0,0) )</td>
<td>( C_n - C_p - C_f + R_q ) ( C_s - R_l )</td>
<td>( C_n - C_p - C_f + R_q - C_s )</td>
</tr>
<tr>
<td>( E_2(0,1) )</td>
<td>( C_n - C_p - C_f + R_q + R_p - R_q ) ( C_s - R_l )</td>
<td>( C_n - C_p - C_f + R_q + R_p - R_q + C_s - R_l )</td>
</tr>
<tr>
<td>( E_3(1,0) )</td>
<td>( C_n - C_p - C_f - R_q ) ( C_o - C_s + R_l )</td>
<td>( C_p + C_f - R_q - C_n + C_o - C_s + R_l )</td>
</tr>
<tr>
<td>( E_4(1,1) )</td>
<td>( C_n - C_p - C_f + R_q - R_q ) ( C_s - C_s + R_l )</td>
<td>( C_p + C_f - R_q - C_n - R_p + R_q - C_o + C_s - R_l )</td>
</tr>
<tr>
<td>( E_5(x^<em>,y^</em>) )</td>
<td>( \frac{C_o - C_s + R_q + R_p}{C_s - R_l} ) ( \frac{C_s - C_p - C_f}{C_s - R_l} )</td>
<td>0</td>
</tr>
</tbody>
</table>

In this case, the equilibrium point \((0,0)\) is the ESS, that is, (not cooperation, not cultivating) is the choice of the general contractors and the labor subcontractors. Under this circumstance, there will be nine situations, as follows:

1) When \( R_q < C_p + C_f - C_n - R_p + R_q \) and \( R_l < C_s - C_o \).

The (not cooperation, not cultivating) strategy will be the choice of the two populations. It means that the compensation to the general contractors and the labor subcontractors does not reach the expected result. The duplicated dynamic trend is presented in Figure 3a.
(2) When \( R_g < C_p + C_f - C_n - R_p + R_q \) and \( C_0 < R_l < C_s \),

With the compensation from the government, labor subcontractors are willing to choose to cultivate a standard workforce. However, compensation for general contractors is not enough to drive them in choosing a “cooperation” strategy. Due to the lack of a market, the system will converge to the equilibrium point \((0,0)\). Figure 3b shows the duplicated dynamic trend.

(3) When \( R_g < C_p + C_f - C_n - R_p + R_q \) and \( R_l > C_s \),

In this situation, the equilibrium point \((0,1)\) is the ESS. It shows that the compensation for labor subcontractors who can cover the cost of cultivating a standard workforce, they will choose the strategy of “cultivating”, no matter whether general contractors participate or not. Figure 3c displays the duplicated dynamic trend.

(4) When \( C_p + C_f - C_n - R_p + R_q < R_g < C_p + C_f - C_n \) and \( R_l < C_s - C_o \),

The strategy (not cooperation, not cultivating) will be the choice of the two populations. In this situation, general contractors are initially willing to cooperate with labor subcontractors on cultivating a standard workforce, while labor subcontractors lack motivation. As a result, the equilibrium point \((0,0)\) is the ESS. Figure 3d displays the duplicated dynamic trend.

(5) When \( C_p + C_f - C_n - R_p + R_q < R_g < C_p + C_f - C_n \) and \( C_s - C_0 < R_l < C_s \),

The equilibrium point \((0,0)\) and \((1,1)\) are the ESSes. The compensation to the two populations can only mitigate the impact of risk to a certain extent. It indicates that general contractors and labor subcontractors will make a choice between (not cooperation, not cultivating) and (cooperation, cultivating). The duplicated dynamic trend is presented in Figure 3e.

(6) When \( C_p + C_f - C_n - R_p + R_q < R_g < C_p + C_f - C_n \) and \( R_l > C_s \),

In this situation, under subsidized by the government, labor subcontractors have a strong willingness to cultivate a standard workforce. The system will converge to the equilibrium point \((1,1)\). Figure 3f shows the duplicated dynamic trend.

(7) When \( R_g > C_p + C_f - C_n \) and \( R_l < C_s - C_o \),

The system will converge to the equilibrium point \((1,0)\). It means that the compensation from the government to general contractors is enough to cover the cost of participating in cultivating a standard workforce, even if labor subcontractors are reluctant to participate in it. However, it is difficult to achieve the desired result and will waste the government’s financial subsidies. The duplicated dynamic trend is presented in Figure 3g.

(8) When \( R_g > C_p + C_f - C_n \) and \( C_s - C_0 < R_l < C_s \),

The equilibrium point \((1,1)\) is the ESS. In this situation, general contractors and labor subcontractors have a strong willingness to take part in establishing a long-term cooperation mechanism to cultivate a standard workforce. Figure 3h shows the duplicated dynamic trend.

(9) When \( R_g > C_p + C_f - C_n \) and \( R_l > C_s \),

In this situation, the game will converge to the equilibrium point \((1,1)\). General contractors and labor subcontractors are subsidized enough by the government to cover the cost of cooperating in cultivating a standard workforce. The duplicated dynamic trend is depicted in Figure 3i.

It can be concluded that the government can drive general contractors and labor subcontractors to cultivate a standard workforce when the compensation reaches to a certain extent. Otherwise, if the compensation is not enough, it may only increase the government’s financial burden and fail to achieve the expected result. Furthermore, no matter how much the subsidy is to general contractors, as long as the subsidy to labor subcontractors reaches \( R_l > C_s \), labor subcontractors will cultivate a standard workforce. As a result, relatively speaking, it is more important to subsidize labor subcontractors rather than general contractors.
4.3. Numerical Simulations

To further analyze how the government influences the dynamic evolution process of general contractors and labor subcontractors when cultivating a standard workforce, this research uses MATLAB 2014a software to conduct numerical simulations. The (not cooperation, not cultivating) strategy is the most likely scenario. Therefore, the authors analyze how to promote the behavior of the two stakeholders to evolve into (cooperation, cultivating) strategy with government participation. Referring to the assignment method in literature [55], the initial value of government participation is set as shown in Table 11.

Table 11. The parameter values.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( R_p )</th>
<th>( R_q )</th>
<th>( R_d )</th>
<th>( R_s )</th>
<th>( R_0 )</th>
<th>( C_p )</th>
<th>( C_f )</th>
<th>( C_n )</th>
<th>( C_o )</th>
<th>( C_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>100</td>
<td>80</td>
<td>60</td>
<td>50</td>
<td>30</td>
<td>40</td>
<td>30</td>
<td>20</td>
<td>20</td>
<td>30</td>
</tr>
</tbody>
</table>

The initial values of x and y are set to 0.9, and the change steps of x and y are set to 0.1. The strategy evolution of the two stakeholders is shown in Figure 4.

![Initial evolution results](image)

Note: The arrows indicate the evolution trend.

Figure 4. Initial evolution results.

From Figure 4, it can be found that regardless of the initial values of x and y, the strategies of general contractors and labor subcontractors will eventually evolve into strategy (not cooperation, not cultivating). In other words, the initial strategy of the two participants has no impact on the final choice (not cooperation, not cultivating). Therefore, without government participation, their ultimate strategic choice would be not to participate in cultivating a standard workforce.

In order to analyze the impact of government participation on the evolution process and investigate which strategies the government adopts can effectively promote the cultivation of a standard workforce, this study will simulate the evolution results of different strategies adopted by the government. According to the parameter values set in Table 11, it can be obtained that \( C_p + C_f - C_n - R_p + R_0 = 30 \), \( C_s - C_o = 10 \), and \( C_p + C_f - C_n = 50 \). Thus, set \( R_{q1} = 20 \), \( R_{q2} = 40 \), \( R_{q3} = 60 \) and \( R_{l1} = 5 \), \( R_{l2} = 15 \), \( R_{l3} = 40 \) to analyze the impact of government incentives on evolutionary outcomes.

1) The impact of government incentives on general contractors

Set the subsidy for labor subcontractors to 0, and the subsidy intensity for general contractors is respectively \( R_{g1} = 20 \), \( R_{g2} = 40 \) and \( R_{g3} = 60 \). The evolution results are shown in Figure 5.
When the government’s subsidy to labor subcontractors is
(a) When the government’s subsidy to general contractors is
(b) When the government’s subsidy to labor subcontractors is
(c) When the government’s subsidy to general contractors is

Figure 5. The evolutionary results of changes in government incentives for general contractors:
(a) $R_{g1} = 20$; (b) $R_{g2} = 40$; (c) $R_{g3} = 60$.

From Figure 5, it can be found that:
(a) When the government’s subsidy to general contractors is $R_{g1} = 20$, due to the low subsidy amount, the final strategy choice for general contractors and labor subcontractors is (not cooperation, not cultivating);
(b) When the government’s subsidy to general contractors is $R_{g2} = 40$, subsidy amount meets $R_{g2} > C_p + C_f - C_w - R_p + R_q$. General contractors are willing to cultivate a standard workforce, but due to the unwillingness of labor subcontractors to participate in cultivating a standard workforce, the ultimate strategy choice for both parties is (not cooperation, not cultivating);
(c) When the government’s subsidy to general contractors is $R_{g3} = 60$, subsidy amount meets $R_{g2} > C_p + C_f - C_w$. Due to the high subsidy amount, general contractors will no longer consider whether labor subcontractors will participate or not, and will make the “cooperation” strategy become their only choice. Without subsidies, labor subcontractors will not participate in the cultivation activity, resulting in the strategic choice of both parties being (cooperation, not cultivating). At this point, it will create the illusion of cultivating a standard workforce, while the cultivation activities have not really carried out. As a result, it will cause an excessive financial burden on the government and a loss of financial resources.

(2) The impact of government incentives on labor subcontractors

Set the subsidy for general contractors to 0, and the subsidy intensity for labor subcontractors is respectively $R_{l1} = 5$, $R_{l2} = 15$ and $R_{l3} = 40$. The evolution results are shown in Figure 6.
(a) When the government’s subsidy to labor subcontractors is $R_{l1} = 5$, due to the low subsidy amount, the final strategy choice for general contractors and labor subcontractors is (not cooperation, not cultivating);
(b) When the government’s subsidy to labor subcontractors is $R_{l2} = 15$, subsidy amount meets $C_s - C_o < R_l < C_s$. Labor subcontractors are willing to cultivate a standard workforce, but due to the unwillingness of general contractors to participate in cultivating a standard workforce, the ultimate strategy choice for both parties is (not cooperation, not cultivating);
(c) When the government’s subsidy to labor subcontractors is \( R_{l2} = 40 \), subsidy amount meets \( R_l > C_s \). Due to the high subsidy amount, labor subcontractors no longer consider the strategic choice behavior of general contractors and will insist on “cultivating” strategy. Without subsidies, general contractors will not participate in the cultivation of a standard workforce, resulting in the ultimate strategic choice of both parties being (not cooperation, cultivating). At this point, despite the lack of participation of general contractors, in reality, labor subcontractors have carried out cultivation activities, which can achieve the goal of cultivating a standard workforce.

![Figure 6](image_url)

Note: The arrows indicate the evolution trend.

**Figure 6.** The evolutionary results of changes in government incentives for labor subcontractors: (a) \( R_{l1} = 5 \); (b) \( R_{l2} = 15 \); (c) \( R_{l3} = 40 \).

(3) The impact of government incentives on both general contractors and labor subcontractors

When the subsidy amount is too high or too low, it will cause one party in the game to no longer consider the strategic behavior of the other party. Thus, the authors will analyze the strategic evolution process of general contractors and labor subcontractors, when \( C_p + C_f - C_n - R_p + R_q < R_s < C_p + C_f - C_n \) and \( C_o - C_s < R_l < C_s \). Set the subsidy for general contractors at \( R_{g2} = 40 \), and the subsidy intensity for labor subcontractors at \( R_{l2} = 15 \). The evolution results are shown in Figure 7.

From Figure 7, general contractors and labor subcontractors will make choices between (not cooperation, not cultivating) and (cooperation, cultivating) strategies. Besides, the process of strategy evolution for both parties will be closely related to the degree of willingness. When one party is unwilling to participate in cultivating a standard workforce, it will greatly dampen the enthusiasm of the other one to participate. Conversely, when one party has a greater willingness to cultivate a standard workforce, it can enhance the motivation of the other one to participate in cultivation.
while productivity will reduce [45]. Labor subcontractors also have two pure strategies, including cultivating a standard workforce or not. The choice of cultivating a standard workforce or employing contingent laborers. If general contractors choose the "cooperation" strategy, they can achieve higher productivity [59], while paying more for it [16]. If general contractors employ contingent laborers, they can save costs [33], while productivity will reduce [45]. Labor subcontractors also have two pure strategies, including cultivating a standard workforce or not. The choice of cultivating a standard workforce will let the labor subcontractors be more competitive in the labor market while bringing more cost and the risk of labor mobility. Or else, if labor subcontractors choose not to cultivate a standard workforce, they will lack competitiveness in the labor market, with fewer risks. In addition, the behavior of general contractors and labor subcontractors will influence the strategy of the other party. They both make a trade-off between the benefit and the cost of cultivating a standard workforce.

The selection of strategies for general contractors and labor subcontractors depends on whether they can benefit from developing a standard workforce. It can be obtained from Figure 2 that (not cooperation, not cultivating) is the main choice of the two participants. If general contractors and labor subcontractors can obtain revenue from it, they will make a trade-off between (cooperation, cultivating) and (not cooperation, not cultivating). Or else, they will choose (not cooperation, not cultivating) strategy. This reflects the current situation of the construction labor market in China, which is not conducive to promoting construction labor professionalization. Thus, without the government’s involvement in the construction labor market, it will be hard to improve the current situation of cultivating a standard workforce.

Due to the deep influence of the government on China’s economic activities, participants in the construction market must follow the regulations formulated by the government. In this context, firms need to pay attention to changes in government policies at all times and avoid losses caused by policy changes. Therefore, government centralization may lead to a lack of flexibility in responding to changing market conditions. This can result in missed opportunities to cultivate a standard workforce if issuing invalid policies. Hence,
the government needs to be more cautious and reasonable when participating in promoting construction labor professionalization.

Subsequently, this study analyzed how the government incentive policy affected the dynamic evolutionary process of cultivating a standard workforce. When the government subsidizes those firms, who choose to take part in cultivating a standard workforce, it can enhance their motivation. According to Section 4, the government has three subside ways to promote the cultivation of a standard workforce. The compensation should reach a certain extent, as follows:

1. When compensation satisfies $R_l > C_o$, although general contractors are reluctant to participate in cultivating a standard workforce, labor subcontractors will insist on cultivating a standard workforce. In this situation, on the one hand, a certain number of standard workforces can be cultivated; on the other hand, only supporting the labor subcontractors can reduce the financial burden of the government, even though the effect of cultivation is less effective for the lack of the general contractors.

2. When compensation satisfies $C_p + C_f - C_o - R_p < R_g < C_p + C_f - C_o$, and $R_l > C_o$ or $R_g > C_p + C_f - C_o$, and $C_s - C_o < R_l < C_o$, the general contractors and the labor subcontractors will cooperate in cultivating a standard workforce. In this situation, the government should make a choice between the two kinds of ways depending on which can reduce the financial burden.

3. When compensation satisfies $R_g > C_p + C_f - C_o$, and $R_l > C_s$, the general contractors and the labor subcontractors will cooperate in cultivating a standard workforce. However, relatively, this is the choice with the heaviest financial burden.

Except for compensation from the government, considering reducing government expenditure, targeted policies should be developed by the government. The following three suggestions are put forward for relevant policy makers in China. First, the government can strengthen the quality supervision of construction projects. It will require construction laborers to have a higher degree of skills so that the profit $R_p$ from employing a standard workforce will increase. Second, the government should regulate the labor market in the construction industry. It will reduce the disorderly mobility of laborers, and will increase the cost of punishment $C_o$. Third, the government needs to establish a workplace training mechanism, which can help relative participation reduce the cost ($C_f$ and $C_s$) in cultivating a standard workforce.

In order to study the behavior of general contractors and labor subcontractors to participate in promoting labor professionalization, the evolutionary game theory model was simplified. For instance, the impacts of the scale of the projects and the type of construction labor were ignored. Therefore, further studies will focus on promoting labor professionalization in a more comprehensive manner.

6. Conclusions

Technological progress is the key to achieving sustainable development in the construction industry. The skill level of construction laborers is closely related to the application of technology [60]. Faced with a shortage of skilled laborers in the construction sector, promoting construction labor professionalization is regarded as an efficient way to solve the problem [9]. As the three-tier management structure of contractor-labor subcontractor-labor is widespread in the construction labor market, general contractors and labor subcontractors are the implementers of promoting construction labor professionalization. Therefore, in this study, an evolutionary game model was built to analyze the behavior of general contractors and labor subcontractors in cultivating a standard workforce.

The contribution of this study involves twofold issues. Firstly, this study carried out a theoretical analysis by using evolutionary game theory to reveal the reasons for the lack of skilled laborer in the construction industry. Besides, practically, this study points out the important role of general contractors and labor subcontractors in promoting labor professionalization, as well as proposing some suggestions to the government about how to
guide contractors and labor subcontractors to effectively train to participate in cultivating standard workforce.

This study aims to analyze the behavior of general contractors and labor subcontractors in promoting labor professionalization. However, the laborers’ own choices can also affect this. Therefore, the authors will examine how laborers’ willingness influences contractors and labor subcontractors in future studies.

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