A RISK ALLOCATION MODEL FOR PPP HIGH-SPEED RAILWAY PROJECTS USING GAME THEORY

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ABSTRACT

Due to the large investment of high-speed railway (HSR) projects, China is trying to adopt the public-private partnership (PPP) model in new projects to mitigate the financial burden of the government. Many studies have shown PPP projects cannot be successfully completed without proper risk allocation. This study firstly identified the risk factors of PPP HSR projects and proposed a bargaining-game model of risk allocation between the government and private sector, which are two parties involved in PPP projects, from a perspective of incomplete information in the planning phase of the HSR project. The risk allocation was analysed as a game that reflects the bargaining process between the government and the private sector, which consists of two processes, i.e. preliminary risk allocation and bargaining for shared risks. The model was then applied to the risk allocation of a proposed project which is the first PPP HSR project in China. By analysing the results of the case study, some suggestions regarding risk prevention were presented for future projects.

Key Words: High-speed railway, public-private partnership (PPP), risk allocation, game theory;

1 INTRODUCTION

High-speed railway (HSR), which in China refers to the railway with a design speed of over 250km/h (including those with reserved capacity for upgrade to the 250 km/h standard) (CRDC and CRCC 2014), is one of the backbones of China's economic development in the past ten years. By the end of 2019, the total operating mileage of HSR in China exceeded 35,000 km, which has ranked first in the world and fulfilled the mission of delivering more than 2.35 billion passengers in 2019. Despite the HSR network in China has greatly promoted communication between different regions, its investment is extremely high (about 20 million RMB yuan per kilometre), which causes huge financial burden to the local government. To ease such a burden, China is trying to attract private capital to join in HSR projects by introducing the PPP model into this sector.

The PPP model, known as the "public-private partnership", is a type of partnership between the government and the private sector to share interests and risks (Holmes et al. 2006). The PPP model can not only effectively satisfy the needs of the Chinese government for HSR infrastructure, but also bring economic benefits to the private sector. However, because of the long concession period, complicated financing process and dynamic environment of the PPP project, many risks potentially exist in the whole life cycle of the project, which are often unclear in the planning stage of the project since the information is incomplete. Previous studies have shown that the proper risk allocation among stakeholders has become the focus of risk management of the PPP project (Li et al. 2017). To reasonable arrange the risks between the government and the private sector, it is necessary to identify the risks that can potentially arise during the implementation of the project, and understand the differences of risk-taking preferences of the parties involved, as well as the process of bargaining and the negotiation under the environment of incomplete information (Li et al. 2017).

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Therefore, this study firstly identified the potential risk factors within the life cycle of the PPP HSR project and proposed a risk allocation model based on game theory under incomplete information, which include two processes, i.e. preliminary risk allocation and bargaining for shared risks, to properly allocate risks between the government and private sector and reduce the risk occurrence probability and risk management cost, and further achieve the success of the project. The risk allocation process is presented in Fig 1.

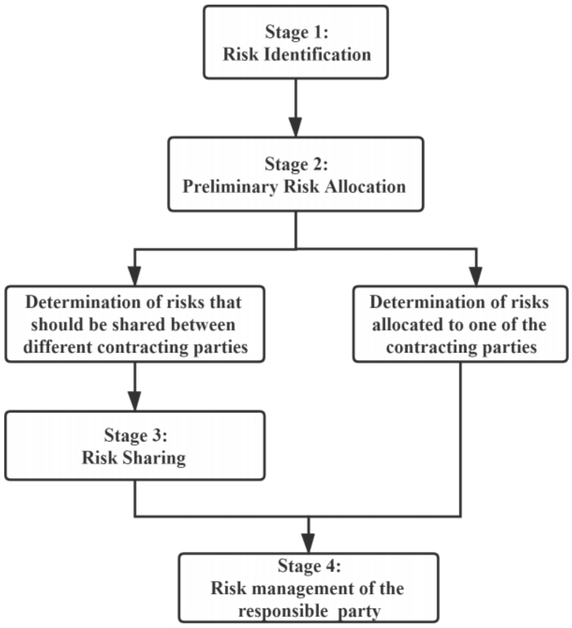

Fig.1 Risk Allocation Process

2 LITERATURE REVIEW

2.1 Risk Allocation in PPP Projects

The intention of risk allocation is to minimise the total risk shouldered by the two parties. According to the studies of Milner (2004) and Lam (2007), the reasonable risk allocation between the government and private sector can be realised by explicitly defining the rights and obligations of parties involved and the risk allocation scheme in the contract. At the same time, the government should formulate reasonable reward policies for the party that take the risk. Li et al. (2005) constructed the risk allocation decision matrix of UK PPP/PFI projects and pointed out that both parties within the project should share risks according to their own preferences. Finally, three schemes of risk allocation were obtained, namely, the risks borne by the private sector, the risks undertaken by the government departments and the risks jointly undertaken by the government and private sector. Shen et al. (2006) showed that the government tends to bear the risk of policies, legal change, approval, etc., while the private sector mainly undertakes the risks within the design, construction and operation stages, and the risks of the interest rate, exchange rate and force majeure are often jointly borne by both parties. Ng and loosemore (2007) took a PPP railway project as a case to study the principle of risk allocation in railway projects and the specific ways to effectively allocate risks. Chen (2011) constructed a risk allocation framework for PPP projects from the perspective of network governance and summarised four factors influencing risk allocation, namely, heterogeneity of participants, communication ability, interaction rules and participation strategies. Ye (2016) constructed a causal structural model between the risk factors in the whole process and early termination of PPP projects and identified the key risk factors leading to early termination of PPP projects. He pointed out that unreasonable risk allocation often leads to early termination of projects.

So far, not many studies about risk allocation in PPP HSR projects have been found, this is because the PPP model is recently introduced in this sector, and yet few studies were carried out.

2.2 Game Theory

Game theory is a methodology to understand the rational behaviours of two or more parties with a struggle to make interactive decisions (Song et al., 2017). Its essence is to analyse the participants under certain conditions, by constantly considering the behaviour of other participants, predicting the results of interaction with their own actions, and then conducting several iterative discussions to select the most favourable behaviour decision and achieve their own goals. The significance of the theory is to determine whether the optimal decision exists in the process of struggle and can be realised in this way (Nasirzadeh et al., 2015).

Since the game theory was established, it has been applied for risk allocation in PPP projects by many researchers. Medda (2007) conducted a case study on PPP transportation infrastructure projects and discussed the optimal risk allocation and selection strategy using game theory. Based on the Shapley value, Leng and Wang (2013) compared the properties of benefit distribution of PPP infrastructure projects and established the benefit distribution model for PPP infrastructure projects. Kang et al. (2013) constructed a game model to compute the reasonable amount of tax and subsidy in PPP projects under the situation of the equilibrium position of the government and private sector, and the results showed that the amount was not affected by the bargaining abilities of both parties. Li et al. (2013) established a bargaining game model between the government and private sector based on the asymmetry of the status of the two parties and explored optimal risk allocation proportion. Ge et al. (2015) analysed the influence of risk preference on the result of risk allocation through a tripartite dynamic game model of PPP projects.

Although a variety of methodologies have been proposed to deal with interest conflicts within partnerships, the results of game theory are often closer to practice and can reflect the behaviour of participants more accurately, which is often ignored by the traditional multi-criteria optimisation methods. Using game theory, stakeholders can reach a unique point that is ideal and equitable to all participants (Nasirzadeh et al., 2016).

3 RISK IDENTIFICATION

Correctly identifying the risks within the PPP HSR project is the prerequisite of optimal risk allocation (Li et al. 2017). Some of the risks in other PPP transportation infrastructures can be references, such as highway projects, in which the PPP model has already been widely applied. However, compared with other transportation infrastructure projects, the HSR project is characterised by great investment, technological complexity and long duration (Zhang et al., 2016), which can lead to other risks during its implementation. Also, in China, HSR projects are motivated by not only economics but also politics, previous HSRs are all operated by the government or state-owned enterprises; therefore, some political risks can be triggered when the PPP model is applied.

To identify the risks of PPP HSR projects, a risk list was summarised through literature review and analysing previous projects. Then, the Delphi experts' survey method (Hasson et al., 2000) was used to get the views of the experts in the railway sector through a questionnaire. 25 respondents were invited, which included government, private enterprises, design institutes, consulting organisations. The questionnaire was designed to be anonymous, to get more accurate and neutral answers. The questionnaire contained a list of potential risk factors obtained, and the respondents can choose to agree or disagree with the existence of the risks within the project. Also, the respondents can suggest the risks that are not included in the given list. Finally, 36 risk factors were identified, which can be divided into three levels, i.e. macroscopic level, mesoscopic level and microscopic level, and each level includes a few first-level risks, as shown in Table 1. Macroscopic risks, as the name suggests, are risks from outside of the project, including political risk, legal risk, etc.; the mesoscopic risks are internal risks of the project, which are classified through time sequence, meaning financing stage, design stage, construction stage and operation stage. The microscopic risks are also the endogenous risks of the project, but they are mainly incurred by the cooperative relationship between the project participants being fragile due to their different purposes and roles in the project.

Table 1

Risk list

Level	First-level risk	Second-level risk
Macroscopic level	Political risk	government intervention
		Government credibility
		Public opposition
		expropriation and nationalization
		Delay in approval
		Poor political decision making
	Legal risk	Legal change
		Imperfect legal system

Table 1 (Continued)

Risk list

Level	First-level risk	Second-level risk
Macroscopic level	Economic risks	Exchange rate change Interest rate change Inflation Market demand change
	Natural risk	Force majeure Geological condition Weather condition
Mesoscopic level	Financing stage risk	Financial feasibility Financial cost Project attraction
	Design stage risk	Design defects
	Construction stage risk	Design change Safety Construction costs overruns Later design change Completion risk Technical problems Project quality
	Operation stage risk	Operating costs overruns Maintenance costs overruns Passenger demand Charge change Market competition
Microscopic level	Relationship risk	Rights, responsibilities, and risk allocation between the parties Cooperation and trust Private investors change Lack of PPP experience
	Third-party risk	Third-party risk

4 RISK ALLOCATION MODEL

Some of the risks involved in a PPP project tend to be exclusively taken by the government or the private sector, while other risks should be shared (Nasirzadeh et al., 2016). Therefore, the first step of the model proposed in this study is to identify the risks that should be independently undertaken as well as those that should be shared.

4.1 Preliminary Risk Allocation

The risk in the project is like a double-edged sword for the participants, who can obtain benefits while paying the cost. The cost paid is often matched with the benefits obtained. If the profit is greater than the cost, then the participants will be willing to take the risk. The above theory is the basis of the preliminary risk allocation model, and due to the complexity of PPP HSR projects, in this study, it is assumed that the benefit and cost are linearly correlated with the corresponding risk to simplify the analysis, therefore:

$$G_i = g_i^1\gamma^1 + g_i^2\gamma^2 + \cdots + g_i^j\gamma^j + \cdots + g_i^n\gamma^n,\ i=1,2 \tag{1}$$

$$C_i = c_i^1\gamma^1 + c_i^2\gamma^2 + \cdots + c_i^j\gamma^j + \cdots + c_i^n\gamma^n,\ i=1,2 \tag{2}$$

Where: G_i refers to the benefit obtained by party *i*; C_i refers to the cost to party *i*; γ^j refers to the value of risk *j*; g_i^j refers to benefit coefficient in terms of party *i* taking risk *j*; c_i^j refers to cost coefficient in terms of party *i* taking risk *j*; *i*=1 refers to the government and *i*=2 refers to the private sector.

Therefore, the net benefit obtained by the participants is as follows:

$$R_i = G_i - C_i = \sum_{j=1}^{n}[(g_i^j - c_i^j)\times \gamma^j] = \sum_{j=1}^{n}[\lambda_i^j \times \gamma^j],\ i=1,2 \tag{3}$$

The λ_i^j is the risk preference coefficient. If $\lambda_i^j = g_i^j - c_i^j > 0$, the participates can make profits by taking risk *j*, therefore, they are willing to take it and the preliminary risk allocation is based on this preference. Since the participants have only two options when facing a certain risk, that is "to take" or "not to take", therefore, there are two situations:

(1) If $\lambda_1^j > 0$, $\lambda_2^j < 0$ or $\lambda_1^j < 0$, $\lambda_2^j > 0$, the response strategies of the government and the private sector to the risk are (to take, not to take) or (not to take, to take). In this situation, only one party would like to take the risk, therefore, the risk should be taken by that party.

(2) If $\lambda_1^j > 0$, $\lambda_2^j > 0$ or $\lambda_1^j < 0$, $\lambda_2^j < 0$, the response strategies of the government and the private sector to the risk are (to take, to take) or (not to take, not to take), which means both parties are willing or not willing to undertake the risk. In this situation, the best solution is to share the risk by the two parties involved. Details of computing the optimal risk sharing ratio among the two parties to maximise the overall interests of the project under incomplete information are presented in the next section.

4.2 Risk Sharing under Incomplete Information

During the early stage of a PPP HSR project, much of the information is incomplete and unclear to both parties involved, which makes it difficult for the parties to make the right decision during the bargaining negotiation. To tackle the incomplete information, Harsanyi (1967) introduced the Harsanyi transformation to convert such incomplete information into complete but imperfect information. The most critical point of the Harsanyi transformation is to assume that the participants within the bargaining game know the probability of each other's strategy, despite they do not know what specific strategies will be taken (Harsanyi, 1967).

Therefore, based on the Harsanyi transformation, some assumptions are set in this study:

(1) Both participants are independent and rational, which means the purpose of both parties is to pursue a strategy that can be accepted by both parties to successfully accomplish the project and maximise the overall interests.

(2) It is the government that makes the offer first since they hold a dominant position in most PPP projects.

(3) The two parties incompletely know about the strategy of the other side, but one can estimate the probable strategy of the other.

(4) The risk ratio taken by the government is *p*, and thus the private sector takes 1-*p* of the risk, and the process of the game is to bargain for the value of *p*.

(5) The cost can be incurred by the bargaining process (e.g. costs of negotiation, time delay), which, in this study, is denoted by bargaining cost coefficient δ ($1<\delta$) (Fishburn and Rubinstein, 1982). δ_1 refers to the bargaining cost coefficient of the government, δ_2 refers to the bargaining cost coefficient of the private sector. Due to the powerful position of the government, it is assumed that $1 < \delta_1 < \delta_2$, and more negotiation rounds will cause more cost to both parties.

(6) The government tends to transfer a part of their risk to the private sector due to their stronger position, the transferred risk is denoted as *t*, $0 \le t \le p$.

4.2.1 Bargaining Game Model Construction

According to the above assumptions, in the first round of the negotiation, the government will make an offer and the private sector can accept or decline it. If the private sector accepts the offer, the negotiation ends; otherwise, it will be postponed to the second round. In the next round, the private sector will propose a counteroffer and the government will accept it or not. These two rounds can be repeated several times until a consensus is reached. Therefore, the theoretical model is as follows.

In the first round of negotiation, the government firstly suggest the risk ratio that is taken by itself, which is denoted as p_1, and the risk allocated to the private sector is 1-p_1. In addition, as assumed above, there is a possibility of k_1 that the government will transfer t_1 of the risk to the private sector. As a result, the risk expectations taken by the government and the private sector respectively are:

$$R'_{G1} = k_1 (p_1 - t_1) \tag{4}$$

$$R'_{P1} = k_1 (1 - p_1 + t_1) \tag{5}$$

Also, there is a possibility of 1- k_1 that the government will not transfer any additional risk to the private sector. In this situation, the risk expectations taken by the government and the private sector are:

$$R''_{G1} = (1 - k_1)\, p_1 \tag{6}$$

$$R''_{P1} = (1 - k_1)\, (1 - p_1) \tag{7}$$

Therefore, in the first round of negotiation, the risk expectations of the two parties are:

$$R_{G1} = R'_{G1} + R''_{G1} = k_1 (p_1 - t_1) + (1 - k_1)\, p_1 \tag{8}$$

$$R_{P1} = R'_{P1} + R''_{P1} = k_1 (1 - p_1 + t_1) + (1 - k_1)\, (1 - p_1) \tag{9}$$

If the private sector cannot accept the government's offer, the negotiation comes to the second round.

In the second round, the private sector firstly proposes to take p_2 of the risk, and 1-p_2 of the risk is allocated to the government. Similarly, the government has a k_1 chance of transferring t_2 of the risk to the private sector. Meanwhile, additional costs will be incurred by the negotiation, therefore, the risk expectations taken by the government and the private sector are:

$$R'_{G2} = k_1 \delta_1 (p_2 - t_2) \tag{10}$$

$$R'_{P2} = k_1 \delta_2 (1 - p_2 + t_2) \tag{11}$$

Also, there is a possibility of 1-k_1 that the government does not transfer further risk to the private sector. In this scenario, the risk expectations undertaken by the parties are:

$$R''_{G2} = \delta_1 (1 - k_1)\, p_2 \tag{12}$$

$$R''_{P2} = \delta_2 (1 - k_1)\, (1 - p_2) \tag{13}$$

Therefore, the total risk expectations allocated to the two parties in this round are:

$$R_{G2} = R'_{G2} + R''_{G2} = k_1 \delta_1 (p_2 - t_2) + \delta_1 (1 - k_1)\, p_2 \tag{14}$$

$$R_{P2} = R'_{P2} + R''_{P2} = k_1 \delta_2 (1 - p_2 + t_2) + \delta_2 (1 - k_1)\, (1 - p_2) \tag{15}$$

Similarly, when it comes into the third round, the risk expectations taken by the two participants are:

$$R_{G3} = R'_{G3} + R''_{G3} = k_1 \delta_1^{\,2} (p_3 - t_3) + \delta_1^{\,2} (1 - k_1)\, p_3 \tag{16}$$

$$R_{P3} = R'_{P2} + R''_{P2} = k_1 \delta_2^{\,2} (1 - p_3 + t_3) + \delta_2^{\,2} (1 - k_1)\, (1 - p_3) \tag{17}$$

If the two sides still cannot reach an agreement on the risk sharing proportion until then, the above bargaining processes will continue until a consensus is reached, which is an infinite bargaining game. Therefore, according to the above analysis, it can be further concluded that in the n th (n=1, 2, 3, ...) round, the risk expectations undertaken by the government and the private sector is as follows:

$$R_{Gn} = R'_{Gn} + R''_{Gn} = k_1 \delta_1^{\,n-1} (p_n - t_n) + \delta_1^{\,n-1} (1 - k_1)\, p_n \tag{18}$$

$$R_{Pn} = R'_{Pn} + R''_{Pn} = k_1 \delta_2^{\,n-1} (1 - p_n + t_n) + \delta_2^{\,n-1} (1 - k_1)\, (1 - p_n) \tag{19}$$

4.2.2 Solution of the Bargaining Game Model

To solve the above model, the reverse induction method is used to solve the model. In an infinite bargaining game, the results are consistent no matter which round the reverse point is set (Shaked and Sutton, 1984). In this study, the reverse point is firstly set in the third round.

In the scheme proposed by the private sector in the second round, if the government's risk expectation R_{G2} is greater than the government's risk expectation R_{G3} in the government's proposal in the third round, the government will not agree with the private sector's plan in the second round. However, the private sector eagerly anticipates their proposal can be passed, since the greater cost will be arisen due to the additional rounds of negotiation and the loss of the private sector is higher than that of the government. Therefore, to persuade the government to accept the offer, the private sector tends to make R_{G2} not greater than R_{G3} while reducing its risk R_{P2} as much as possible for its profit. The best proposal for the private sector is to make R_{G2}=R_{G3}, which leads to:

$$k_1\delta_1(p_2 - t_2) + \delta_1(1-k_1)p_2 = k_1\delta_1^2(p_3 - t_3) + \delta_1^2(1-k_1)p_3 \tag{20}$$

$$p_2 = \delta_1 p_3 + k_1 t_2 - \delta_1 k_1 t_3 \tag{21}$$

Applying equation (21) to (15), the private sector's risk ratios in the second and third rounds are:

$$R_{Q2} = \delta_2(1 - \delta_1 p_3 + k_1\delta_1 t_3) \tag{22}$$

$$R_{Q3} = \delta_2^2(1 - P_3 + k_1 t_3) \tag{23}$$

Where: $1<\delta_1<\delta_2$, $0<k_1<1$, $t_3<p_3$.

Then

$$R_{Q2} - R_{Q3} = \delta_2[(1-\delta_2) - (\delta_1 - \delta_2)(k_1 t_3 - p_3)] < 0 \tag{24}$$

which indicates that the private sector's risk expectation in the second round is less than that in the third round, therefore it will not let the negotiation come to the third round.

Similarly, when the reverse point is set in the first round, if the risk expectation R_{p1} undertaken by the private sector is higher than R_{p2} in the second round, then in order to maximise its own interests, the private sector will refuse the government's proposal in the first round, and the negotiation will enter the second round. Meanwhile, the government is also not willing to negotiate another round to minimise the cost and time of negotiation, therefore, the government should ensure the risk R_{p1} undertaken by the private sector in the first round is not greater than r_{p2} in the second round while maximising their own interests in the first round of negotiation. Therefore, the optimal strategy is to let R_{p1}= R_{p2}, which leads to:

$$k_1(1 - p_1 + t_1) + (1-k_1)(1-p_1) = k_1\delta_2(1 - p_2 + t_2) + \delta_2(1-k_1)(1-p_2) \tag{25}$$

then

$$p_1 = 1 - k_1 t_1 - \delta_2(1 - \delta_1 p_3 + \delta_1 k_1 t_3) \tag{26}$$

According to the Harsanyi transformation, in an infinite bargaining game, no matter which round the reverse point is set in, the results are consistent (Shaked and Sutton 1984), thus p_1=p_3.

Assuming the risks transferred by the government to the private sector are consistent, which is t, the final optimal risk allocation ratios of the two parties are:

$$p = (\delta_2 - 1)/(\delta_1\delta_2 - 1) + k_1 t \tag{27}$$

$$1 - p = (\delta_1\delta_2 - \delta_2)/(\delta_1\delta_2 - 1) - k_1 t \tag{28}$$

The above risk allocation ratios are the theoretical optimal results that maximise the overall benefits of the two parties. However, since the government holds a dominant position, it tends to transfer risk ratio k_1t to the private sector, therefore, the actual ratios are $(\delta_2 - 1)/(\delta_1\delta_2 - 1)$ and $(\delta_1\delta_2 - \delta_2)/(\delta_1\delta_2 - 1)$ for the government and the private sector respectively.

5 CASE STUDY

The application of the theoretical model for PPP HSR was demonstrated using the case of the Hangzhou-Shaoxing-Taizhou Intercity Railway. This railway is the first PPP HSR in China, of which the total investment is more than ¥44.8 billion. The project commenced in 2017 and the concession period is 34 years (including the 4-year construction period and operation period). The general route of the project is shown in Fig. 2.

Fig. 2 General Route of the Hangzhou-Shaoxing-Taizhou Intercity Railway

5.1 Preliminary Risk Allocation

According to the analysis in section 2.1, the preliminary risk allocation is based on the risk preference coefficient λ. If $\lambda_1^j > 0$, $\lambda_2^j < 0$, the risk j should be allocated to the government; if $\lambda_1^j < 0$, $\lambda_2^j > 0$, the private sector will take the risk; if $\lambda_1^j > 0$, $\lambda_2^j > 0$ or $\lambda_1^j < 0$, $\lambda_2^j < 0$, the risk should be shared by the two parties. Therefore, another questionnaire was handed to 20 experts involved in this project to obtain their opinions about the risk preferences of the two parties. Each risk preference coefficient has 4 potential values, the meanings of which are shown in table 2, and each respondent was invited to choose the suitable values they believe. For a certain risk, the value that was chosen by the respondents most is the risk preference coefficient of that risk. The results of the risk preference coefficient are presented in table 3.

Table 2

Meanings of the risk preference coefficient values

Value	-1	-0.5	0.5	1
Meaning	Very unwilling	Unwilling	Willing	Very willing

Table 3

Preliminary Risk Allocation of Hangzhou-Shaoxing-Taizhou Intercity Railway Project

Risk		Risk preference coefficient		Risk allocation
First level risk	Second level risk	Government	Private sector	
Political risk	Government intervention	$\lambda_1^1 = 1 > 0$	$\lambda_2^1 = -1 < 0$	Government
	Government credibility	$\lambda_1^2 = 1 > 0$	$\lambda_2^2 = -1 < 0$	Government
	Public opposition	$\lambda_1^3 = 1 > 0$	$\lambda_2^3 = -1 < 0$	Government
	Expropriation and nationalization	$\lambda_1^4 = 1 > 0$	$\lambda_2^4 = -1 < 0$	Government
	Delay in approval	$\lambda_1^5 = 1 > 0$	$\lambda_2^5 = -1 < 0$	Government
	Poor political decision making	$\lambda_1^6 = 1 > 0$	$\lambda_2^6 = -1 < 0$	Government
Legal risk	Legal change	$\lambda_1^7 = 1 > 0$	$\lambda_2^7 = -1 < 0$	Government
	Imperfect legal system	$\lambda_1^8 = 1 > 0$	$\lambda_2^8 = -1 < 0$	Government

Table 3 (Continued)

Preliminary Risk Allocation of Hangzhou-Shaoxing-Taizhou Intercity Railway Project

Risk		Risk preference coefficient		Risk allocation
First level risk	Second level risk	Government	Private sector	
Economic risks	Exchange rate change	$\lambda_1^9 = -0.5 < 0$	$\lambda_2^9 = 0.5 > 0$	Private
	Interest rate change	$\lambda_1^{10} = -0.5 < 0$	$\lambda_2^{10} = -0.5 < 0$	Shared
	Inflation	$\lambda_1^{11} = -0.5 < 0$	$\lambda_2^{11} = -0.5 < 0$	Shared
	Market demand change	$\lambda_1^{12} = -0.5 < 0$	$\lambda_2^{12} = -0.5 < 0$	Shared
Natural risk	Force majeure	$\lambda_1^{13} = -1 < 0$	$\lambda_2^{13} = -0.5 < 0$	Shared
	Geological condition	$\lambda_1^{14} = -1 < 0$	$\lambda_2^{14} = 1 > 0$	Private
	Weather condition	$\lambda_1^{15} = -1 < 0$	$\lambda_2^{15} = 1 > 0$	Private
Financing stage risk	Financial feasibility	$\lambda_1^{16} = -0.5 < 0$	$\lambda_2^{16} = 1 > 0$	Private
	Financial cost	$\lambda_1^{17} = 1 > 0$	$\lambda_2^{17} = 1 > 0$	Shared
	Project attraction	$\lambda_1^{18} = -0.5 < 0$	$\lambda_2^{18} = 1 > 0$	Private
Design stage risk	Design defects	$\lambda_1^{19} = -0.5 < 0$	$\lambda_2^{19} = 0.5 > 0$	Private
	Design change	$\lambda_1^{20} = 0.5 > 0$	$\lambda_2^{20} = -0.5 < 0$	Government
Construction stage risk	Safety	$\lambda_1^{21} = -0.5 < 0$	$\lambda_2^{21} = 0.5 > 0$	Private
	Construction costs overruns	$\lambda_1^{22} = -1 < 0$	$\lambda_2^{22} = -1 < 0$	Shared
	Later design change	$\lambda_1^{23} = -1 < 0$	$\lambda_2^{23} = -1 < 0$	Shared
	Completion risk	$\lambda_1^{24} = -0.5 < 0$	$\lambda_2^{24} = 1 > 0$	Private
	Technical problems	$\lambda_1^{25} = -0.5 < 0$	$\lambda_2^{25} = 1 > 0$	Private
	Project quality	$\lambda_1^{26} = -0.5 < 0$	$\lambda_2^{26} = 1 > 0$	Private
Operation stage risk	Operating costs overruns	$\lambda_1^{27} = -1 < 0$	$\lambda_2^{27} = 1 > 0$	Private
	Maintenance costs overruns	$\lambda_1^{28} = -1 < 0$	$\lambda_2^{28} = 1 > 0$	Private
	Passenger demand	$\lambda_1^{29} = -0.5 < 0$	$\lambda_2^{29} = -0.5 < 0$	Shared
	Charge change	$\lambda_1^{30} = -1 < 0$	$\lambda_2^{30} = 1 > 0$	Private
	Market competition	$\lambda_1^{31} = -0.5 < 0$	$\lambda_2^{31} = -0.5 < 0$	Shared
Relationship risk	Rights, responsibilities, and risk allocation between the parties	$\lambda_1^{32} = 0.5 > 0$	$\lambda_2^{32} = 0.5 > 0$	Shared
	Cooperation and trust	$\lambda_1^{33} = -1 < 0$	$\lambda_2^{33} = 1 > 0$	Private
	Private investors change	$\lambda_1^{34} = -1 < 0$	$\lambda_2^{34} = 1 > 0$	Private
	Lack of PPP experience	$\lambda_1^{35} = -1 < 0$	$\lambda_2^{35} = 1 > 0$	Private
Third-party risk	Third-party risk	$\lambda_1^{36} = 1 > 0$	$\lambda_2^{36} = -1 < 0$	Government

From the results of the survey, in the preliminary allocation, ten risks are allocated to the government and sixteen risks are taken by the private sector. It is noteworthy that most of the risks independently taken by the government are macroscopic risks, which can be explained by the government's greater ability to control the problems on a macro level. On the other hand, most of the risks exclusively taken by the private sector are mesoscopic and microscopic risks, this is because most of the mesoscopic and microscopic risks are directly related to the implementation of the project, as the project direct beneficiary and executor, it is reasonable for the private sector to take more such risks.

Ten risks are shared by both parties: interest rate change; inflation; market demand change; force majeure; financial cost; construction costs overruns; later design change; passenger demand; market competition; Rights, responsibilities, and risk allocation between the parties. The allocation ratios of the ten shared risks are obtained through the bargaining game model, which is shown in the next section.

5.2 Allocation Ratios of Shared Risks

To compute the optimal risk allocation ratios, the values of the four parameters k_1, δ_1, δ_2, t are needed. Therefore, the former 20 participates in this case study were invited again to obtain the values of the parameters through a questionnaire. The respondents were asked questions about the proper values of the four parameters they think and the mean parameter values given by them are shown in table 4.

Table 4 Related parameter values

Risk factor	k_1	δ_1	δ_2	t
interest rate change	0.61	1.09	1.18	0.09
inflation	0.67	1.14	1.18	0.10
market demand change	0.55	1.17	1.18	0.10
force majeure	0.53	1.09	1.13	0.07
financial cost	0.59	1.08	1.14	0.06
construction costs overruns	0.8	1.12	1.19	0.11
later design change	0.65	1.08	1.12	0.08
passenger demand	0.80	1.06	1.11	0.07
market competition	0.78	1.07	1.13	0.10
Rights, responsibilities, and risk allocation between the parties	0.61	1.11	1.2	0.09

Taking the interest rate change as an example, the risk allocation ratios of the government and private sector is calculated according to the theoretical model in 2.2. By applying the equation with the parameters above, the optimal risk allocation ratio of the interest rate change for the government is:

$$\begin{aligned} p &= (\delta_2 - 1)/(\delta_1\delta_2 - 1) + k_1 t \\ &= (1.18 - 1)/(1.09 \times 1.18 - 1) + 0.61 \times 0.09 = 68.38\% \end{aligned} \tag{29}$$

The risk ratio taken by the private sector is:

$$1\text{-}p=31.62\% \tag{30}$$

Moreover, the government has a 61% chance of transferring 9% risk to the private sector, in this scenario, the risk taken by the government is: p-0.61×0.09=62.89%, and the risk undertaken by the private sector is 1-62.89 % =37.11 %. The optimal risk allocation ratios of the other nine risk factors in both scenarios are calculated similarly, and the final allocation results are shown in Table 5.

Table 5 Risk Taken Proportions of Shared Risks

Risk factors	Before transferring		Probability of transferring	After transferring	
	Government	Private sector		Government	Private sector
interest rate change	68.38%	31.62%	61%	62.89%	37.11%
inflation	58.84%	41.16%	67%	52.14%	47.86%
market demand change	52.79%	47.21%	55%	47.29%	52.71%
force majeure	57.72%	42.28%	23%	56.11%	43.89%
financial cost	64.09%	35.91%	59%	60.55%	39.45%
construction costs overruns	65.89%	34.11%	80%	57.09%	42.91%
later design change	62.45%	37.55%	65%	57.25%	42.75%
passenger demand	68.17%	31.83%	84%	62.29%	37.71%
market competition	69.97%	30.03%	78%	62.17%	37.83%
Rights, responsibilities, and risk allocation between the parties	65.73%	34.27%	61%	60.24%	39.76%

As can be seen from Table 5, in the case of incomplete information, the government tends to use its powerful position to exert great pressure on the private sector to transfer their risks, consequently, the actual risk rate taken by the government is usually lower than the risk rate that it normally takes. Among the risks listed above, when the project is faced with risks of construction cost overruns and market competition, the risk ratios transferred by the government to the private sector are the highest, which are 8.8% and 7.8% respectively. This indicates that the government hopes that enterprises can find ways out on their own when confronted with scenarios of insufficient funds and fierce market competition.

6 CONCLUSIONS AND RECOMMENDATIONS

Because of the large investment, long concession period and technological complexity of the PPP HSR project (Zhang et al., 2016), there are many potential risk factors within its life cycle, which may trigger severe damage to both private enterprise and the public. This study firstly identified a risk list of the PPP HSR project through literature review, case analysis and Delphi experts' investigation method. 36 risk factors were identified, which can be divided into ten major categories. Then, this study proposed a risk allocation model, in which those risks are preliminarily allocated according to the preferences of the government and private sector, which depends on the cost and benefit of taking the risk. After the preliminary allocation, some risks are exclusively taken by one of the parties and for the risks that cannot be independently undertaken by any of the parties, the risk sharing ratios are computed through a bargaining game model based on the principle of government priority bidding due to the dominant position of the government.

According to the analysis of the model, the proportion of the risk sharing between the two parties is related to the bargaining cost coefficient and the probability of the government transferring the risk to the private sector. Both bargaining cost coefficient and risk transferring probability are related to the position asymmetry of the two parties. The more obvious the asymmetry is, the greater the bargaining cost coefficient and risk transferring probability will be.

Finally, the risk allocation model was used to determine the risk allocation scheme of Hangzhou-Shaoxing-Taizhou Intercity Railway, which is the first PPP HSR in China, and a reasonable risk allocation plan was obtained, which could provide reference values for the risk allocation of future the PPP HSR projects. Also, according to the case study, several recommendations were made for the development of future projects:

Establish a reasonable risk allocation mechanism. Many risks of the project cannot be borne exclusively by one of the participants, thus it should be effectively shared. A reasonable risk allocation is the prerequisite of the successful implementation of the project. Therefore, it is necessary to establish a reasonable risk allocation mechanism to increase the enthusiasm of the private sector to join in HSR projects.

Give full play to government functions. Introducing the PPP model into PPP HSR projects is an important step to introduce competition in the railway industry. The government should locate its own functions accurately. The government's role should shift from a constructor to an assistant of the private sector to ensure supervising and completing the project. In this process, the government should provide the necessary support and help during the implementation of the project. Its responsibility is not only to guarantee the private sector receive their returns but also to ensure the interest of the public. It also should be responsible for the overall organisation and coordination of the project, and reasonably allocate the rights and responsibilities of all participants.

Develop a risk management plan and an exit mechanism for the private sector. Before participating in the PPP HSR project, the private sector should fully analyse the potential risks of the project and make contingency plans to deal with them. Also, an exit mechanism for the private sector should be formulated in the contract, in case the risk is too much for the private sector to handle. The private sector should necessarily give up in time according to the exit mechanism in such a situation, to avoid causing greater damage to itself as well as the public society.

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