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Risk evaluation of technology innovation in Chinese oil and gas industry

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Abstract: Oil and gas industries are technology intensive and appropriate risk evaluation is necessary. The Chinese oil and gas industry is in the development phase, thus risk assessments and mitigation is more important than pushing technological innovation. This paper compiles research of other experts in the field and evaluates innovation risk by using a multi-hierarchy grey method. The result shows that the technology innovation risk for Chinas oil and gas industry is relatively high. Finally, this paper proposes some suitable measures that may decrease risk levels.

Keywords: risk evaluation; technology innovation; oil and gas industry; risk and uncertainty; multi-hierarchy grey method.

1. INTRODUCTION

Technology innovation is a process that can make manufacturing more efficient by reforming production conditions and factors. It is an important parameter for reducing costs and enhancing economic competitiveness — especially in a globalized market. It is widely recognized that oil and gas production is technology intensive, as innovation is crucial for efficient use of existing resources and for future exploration. In China, oil and gas industry has been developing for about 60 years and several important changes have arisen from innovation and new technologies. However, technology innovation has related risks and uncertainties that can lead to failure as certain innovations fail to live up to the expectations. Consequently, it is imperative to conduct careful risk evaluation to avoid pitfalls and attempt to identify successful alternatives. Such evaluations will support a continued growth and development of Chinese oil and gas industry.

Risk evaluation on technology innovation emerged as a separate research field in the 1950s. Since then, many researchers have expanded the underlying framework. Faith and Barry (2003) defines technology innovation risk as the possibility of technology innovation failure caused by technological uncertainty, market conditions, finance, policies, laws, etc. It is often practical to divide technology innovation risk into two subclasses: technology risk and market risk (Moriarty and Kosnik, 1989). It is sound and sensible to depict the risk of technology innovation by establishing suitable risk indexes according to some appropriate methodology (Rubenstein et al., 1976; Cooper, 1979; Benaroch, 2001). There are several existing approaches for technology innovation risk evaluation. For example, Abt (1979) developed a model based on the mean square deviation and the expected lost sales. Dosi (1982) described probabilistic methods, while alternative methodologies were initially proposed by Ansoff (1958) and Hart (1966).

In recent years, research on technology innovation risk has diffused into many sectors. Gulcin, Orhan and Guelfem (2007) examined software development project risks and proposed a multi-criteria decision-making approach based on the Choquet integral for identifying the most important risk factors. Hoecht and Trott (2006) investigated the innovation-related risks that can arise from strategic outsourcing and adopted a “*trust, collaboration and network*”-perspective for their analysis. Ghadim, Pannell and Burton (2005) studied risks in crop innovation and developed empirical models based on a theoretical framework that conceptualizes adoption as a dynamic decision process involving information acquisition and learning-by-doing by growers who vary in their managerial abilities, risk preferences, and their perceptions of the profitability and riskiness of the innovation. Borchers (2005) explored risk and decision uncertainty in management of wildfires, forest resource values, and new technology.

In China, elementary definitions and methods for risk evaluation were introduced by Xie (1992). Other researchers followed and made important contributions. For example, Wu (2004) proposed a risk analysis based on three analysis matrixes and showed new ways to assess technology innovation. Chen et al. (2007) utilized back-propagation (BP) neural networks and obtained equitable results. Wu, Sun and Niu (2008) analyzed differences in technology innovation risks for high-tech enterprises. Xi (2008) used compound hierarchy gray assessment to estimate and control technology innovation risk for enterprises. Xing, Ma and Li (2008) evaluated enterprise technology innovation risks using AHP-Fuzzy comprehensive evaluation method.

Many papers have been written on various evaluation methodologies, case studies or technology risk assessments. From available literature, we can conclude that researchers rarely focus on the oil and gas industry and virtually all studies are done on just a single enterprise. In this paper, we evaluate the technology innovation risk of the entire Chinese oil and gas industry rather than focusing on just one particular company. Such risk evaluations may be more important for policy makers and future Chinese development plans than a similar analysis done on just a single company.

2. METHODOLOGY

This study employs the multi-hierarchy grey method for risk evaluation. It is a combination of combines the analytic hierarchy process (AHP) method and the grey system theory. AHP was originally developed by Saaty (1977) and is a way to decompose complex decision problems into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. Grey systems and grey systems theory are discussed by Deng (1990) and offer a way to study uncertainty in systems with both known and unknown parameters. Consequently, the multi-hierarchy grey method will inherit properties and strengths of its parent methodologies.

The multi-hierarchy grey method consists of seven steps as described in Figure 1. The most important steps are 1, 3 and 4. The index system that serves as an evaluation scale is established in step 1 and must be defined in a systematic and feasible way. Step 3 formulates the judgment matrix, where invited experts from the Chinese oil and gas industry provide their input. These experts should be skillful and well respected for their competence to provide the best possible input. The grey cluster is determined in step 4 and indicates the different risk ranks.

Multi-hierarchy grey analysis has already been used for evaluation of ecological city planning, tourism resources exploration potential, stock quality appraisal and machine tool selection in networked manufacturing. Generally, it has shown to be an effective methodology and this is why it has been chosen for this analysis.

3. EVALUATION PROCESS

3.1 Establishing the evaluation index system

Consideration of the structure and state of the Chinese oil and gas industry allows the establishment of a systematic evaluation index system (Table 1). Technology innovation risk can now be divided into two categories: internal and external risk. Internal risk includes the subcategories technology risk (U_1) and management risk (U_2). The full technology innovation risk (U) contains technology risk (U_1), management risk (U_2) and external risk (U_3) as shown in Table 1.

Further subdivisions can be done in the second hierarchy, giving detailed indexes for the third hierarchy. This index system will help to identify the structure of technology innovation risks in the Chinese oil and gas industry. It is now apparent that several risk and uncertainty factors affect technology innovation. If important risk factors and their contribution to the overall risk are poorly understood before the implementation of a new technology, it may fail after deployment.

Table 1. *Evaluation index system for technology innovation of the Chinese oil and gas industry*

Hierarchy 1	Hierarchy 2	Hierarchy 3
Technology innovation risk (U)	Internal risk	Uncertainty of innovation results (U_{11});
		Uncertainty of innovation prospects (U_{12});
	Management risk (U_2)	Uncertainty of technology life cycle (U_{13});
		Production risk (U_{14})
		Decision risk (U_{21});
		Financial risk (U_{22});
		Talent risk (U_{23});
		Project management risk (U_{24})
	External risk (U_3)	Market risk (U_{31});
		Oil and gas policy risk (U_{32});
		Macroeconomic risk (U_{33});
		Risk of society and culture environment (U_{34})

3.2 Determining the evaluation ranks and weight of each index

The indexes belonging to hierarchy 3 (U_{ij} , $i=1, 2, 3$; $j=1, 2, 3, 4$) in Table 1 must be quantified. Based on a five-point Likert scale method, these indexes are given the values of 1, 2, 3, 4 or 5, corresponding to very low, low, general, high and very high. If the risk is between two ranks, we chose to use 1.5, 2.5, 3.5 and 4.5 for describing intermediate levels. In total, we employ 9 possible ranks for each index.

For hierarchy 2 (U_i , $i=1, 2, 3$), the weights of each index are defined as $W=(w_1, w_2, w_3)$, $w_1+w_2+w_3=1$. In a similar way, weights for hierarchy 3 (U_{ij} , $i=1, 2, 3$; $j=1, 2, 3, 4$) are defined as $W_i=(w_{i1}, w_{i2}, w_{i3}, w_{i4})$, $i=1, 2, 3, 4$, $w_{i1}+w_{i2}+w_{i3}+w_{i4}=1$.

Before proceeding with the evaluation, these weights must be determined. The AHP method offers a suitable way for doing this by establishing a judgement matrix based on inputs from consulted experts. Each weight can be calculated from this judgement matrix using a consistency test. Finally, we get $W=(w_1, w_2, w_3)=(0.408, 0.277, 0.315)$; $W_1=(w_{11}, w_{12}, w_{13}, w_{14})=(0.283, 0.242, 0.216, 0.259)$; $W_2=(w_{21}, w_{22}, w_{23}, w_{24})=(0.301, 0.205, 0.212, 0.282)$; $W_3=(w_{31}, w_{32}, w_{33}, w_{34})=(0.324, 0.299, 0.236, 0.141)$.

3.3 Creating an evaluation matrix by input from experts

The judgment matrix, here denoted D , is used to provide different scores to the indexes in hierarchy 3. This is done from inputs provided by experts from the oil and gas industry. The multi-hierarchy grey method requires a minimum of 4 experts and if there are m experts to give input, it will yield a $12 \times m$

matrix. In this study, we consulted 5 ($m=5$) different experts from the Chinese oil and gas. These experts were carefully chosen to represent balanced and experienced views on the technology innovation of the Chinese oil and gas industry. In matrix D , the row vector shows the scores marked by different experts for one index, while the column vector displays the scores marked by one expert for all indexes. The matrix D is as follows:

$$D = \begin{bmatrix} 3.5 & 4 & 4 & 3.5 & 3.5 \\ 3 & 3.5 & 3.5 & 3 & 3.5 \\ 3.5 & 3.5 & 3.5 & 3 & 3 \\ 2.5 & 2 & 3 & 2.5 & 2 \\ 3.5 & 3 & 4 & 3 & 3.5 \\ 2.5 & 2.5 & 3 & 2.5 & 2 \\ 3 & 2.5 & 3.5 & 3 & 3 \\ 3 & 3.5 & 3.5 & 4 & 3 \\ 3.5 & 3.5 & 3 & 4 & 3.5 \\ 3.5 & 3 & 4 & 3 & 3 \\ 3 & 3.5 & 3.5 & 3 & 3.5 \\ 2 & 2 & 2 & 2 & 2 \end{bmatrix} \Rightarrow \begin{matrix} U_{11} \\ U_{12} \\ U_{13} \\ U_{14} \\ U_{21} \\ U_{22} \\ U_{23} \\ U_{24} \\ U_{31} \\ U_{32} \\ U_{33} \\ U_{34} \end{matrix}$$

3.4 Determining the evaluation grey clusters

The evaluation grey cluster must be determined in the multi-hierarchy grey method. This is done by determining the rank of the evaluation grey cluster, grey degree and definite weighted function (Hartman and Myers, 2000). Evaluation grey clusters are designated as h with $h=1, 2, \dots, g$. For this study, the risk of technology innovation is divided into 5 ranks: very low ($h=1$), low ($h=2$), general ($h=3$), high ($h=4$) and very high ($h=5$). This implies that that $g=5$. After determining the rank of each grey cluster, one can compute the grey degree and definite weighted function for risk evaluation as follows:

- (1) For the first grey cluster “very low ($h=1$)”, the grey degree $\otimes_1 \in [0, 1, 2]$, definite weighted function is f_1 ;
- (2) For the second grey cluster “low ($h=2$)”, the grey degree $\otimes_2 \in [0, 2, 4]$, definite weighted function is f_2 ;
- (3) For the third grey cluster “general ($h=3$)”, the grey degree $\otimes_3 \in [0, 3, 6]$, definite weighted function is f_3 ;
- (4) For the fourth grey cluster “high ($h=4$)”, the grey degree $\otimes_4 \in [0, 4, 8]$, definite weighted function is f_4 ;
- (5) For the fifth grey cluster “very high ($h=5$)”, the grey degree $\otimes_5 \in [0, 5, +\infty]$, definite weighted function is f_5 ;

The five definite weighted functions are also displayed in Figure 2.

3.5 Calculating the weight vectors and weight matrixes

The range of each definite weighted function is determined from Figure 2. The matrix D can be used to calculate grey evaluation coefficients of each index along with weight vector and weight matrix. For index U_{ij} ($i=1, 2, 3; j=1, 2, 3, 4$), we define x_{ijh} as the grey evaluation coefficient belonging to the grey cluster h .

$$x_{ijh} = \sum_{k=1}^m f_h$$

As h belongs to $[1, g]$, this gives x_{ij} as corresponding total grey evaluation coefficient for index U_{ij} .

$$x_{ij} = x_{ij1} + x_{ij2} + \dots + x_{ijg} = \sum_{h=1}^g x_{ijh}$$

The weight of the grey evaluation coefficient belonging to the grey cluster h is r_{ijh} :

$$r_{ijh} = \frac{x_{ijh}}{x_{ij}}$$

All weights are now used to form the weight vector r_{ij} of index U_{ij} when h changes in the interval $[1, g]$.

$$r_{ij} = (r_{ij1}, r_{ij2}, \dots, r_{ijg})$$

The index U_{11} , i.e. uncertainty of innovation results, in the evaluation index system can now be obtained. For U_{11} , we know that $m=5$, $g=5$, then it follows:

When $h=1$, $x_{111}=f_1(3.5)+f_1(4)+f_1(4)+f_1(3.5)+f_1(3.5)=0$;
 When $h=2$, $x_{112}=f_2(3.5)+f_2(4)+f_2(4)+f_2(3.5)+f_2(3.5)=0.75$;
 When $h=3$, $x_{113}=f_3(3.5)+f_3(4)+f_3(4)+f_3(3.5)+f_3(3.5)=3.833$;
 When $h=4$, $x_{114}=f_4(3.5)+f_4(4)+f_4(4)+f_4(3.5)+f_4(3.5)=4.625$;
 When $h=5$, $x_{115}=f_5(3.5)+f_5(4)+f_5(4)+f_5(3.5)+f_5(3.5)=3.7$.

Consequently, the total grey evaluation coefficient for index U_{11} is:

$$x_{11} = \sum_{h=1}^5 x_{11h} = 0 + 0.75 + 3.833 + 4.625 + 3.7 = 12.908$$

Finally, the weight vector r_{11} of index U_{11} can now be calculated from the grey evaluation coefficient and the total grey evaluation coefficient.

$$r_{11} = (0, 0.058, 0.297, 0.358, 0.287)$$

From the index system (Table 1), every index (U_i , $i=1, 2, 3$) belonging to hierarchy 2 has 4 subordinate indexes (U_{ij} , $i=1, 2, 3$; $j=1, 2, 3, 4$) belonging to hierarchy 3. Other weight vectors r_{ij} of indexes U_{ij} can be calculated in the same way. Combining all these weight vectors, we obtain the weight matrix for the indexes U_i ($i=1, 2, 3$). For the first index technology risk (U_1), the weight matrix R_1 is as follows:

$$R_1 = \begin{bmatrix} r_{11} \\ r_{12} \\ r_{13} \\ r_{14} \end{bmatrix} = \begin{bmatrix} 0 & 0.058 & 0.297 & 0.358 & 0.287 \\ 0 & 0.128 & 0.329 & 0.302 & 0.241 \\ 0 & 0.128 & 0.329 & 0.302 & 0.241 \\ 0 & 0.299 & 0.299 & 0.224 & 0.179 \end{bmatrix}$$

In the same way, weight matrixes R_2 , R_3 for management risk (U_2) and external risk (U_3) are as follows:

$$R_2 = \begin{bmatrix} r_{21} \\ r_{22} \\ r_{23} \\ r_{24} \end{bmatrix} = \begin{bmatrix} 0 & 0.111 & 0.321 & 0.315 & 0.252 \\ 0 & 0.277 & 0.308 & 0.231 & 0.185 \\ 0 & 0.184 & 0.319 & 0.276 & 0.221 \\ 0 & 0.111 & 0.321 & 0.315 & 0.252 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} r_{31} \\ r_{32} \\ r_{33} \\ r_{34} \end{bmatrix} = \begin{bmatrix} 0 & 0.095 & 0.305 & 0.333 & 0.267 \\ 0 & 0.128 & 0.329 & 0.302 & 0.241 \\ 0 & 0.128 & 0.329 & 0.302 & 0.241 \\ 0 & 0.390 & 0.260 & 0.195 & 0.156 \end{bmatrix}$$

3.6 Integration evaluation

Using AHP methodology, we now compute the weights of indexes U_{ij} as $W_1 = (w_{11}, w_{12}, w_{13}, w_{14}) = (0.283, 0.242, 0.216, 0.259)$; $W_2 = (w_{21}, w_{22}, w_{23}, w_{24}) = (0.301, 0.205, 0.212, 0.282)$; $W_3 = (w_{31}, w_{32}, w_{33}, w_{34}) = (0.324, 0.299, 0.236, 0.141)$. Together with the weight matrixes R_1 , R_2 and R_3 , the integration evaluation for U_1 , U_2 and U_3 can now be calculated as B_1 , B_2 and B_3 .

$$B_1 = W_1 \cdot R_1 = (0, 0.152, 0.312, 0.298, 0.238)$$

$$B_2 = W_2 \cdot R_2 = (0, 0.161, 0.318, 0.290, 0.232)$$

$$B_3 = W_3 \cdot R_3 = (0, 0.154, 0.311, 0.297, 0.237)$$

Using the weight $W = (w_1, w_2, w_3) = (0.408, 0.277, 0.315)$ and the matrix $(B_1, B_2, B_3)^T$, the integration evaluation for risk of technology innovation (U) belonging to hierarchy 1 is obtained and denoted B .

$$B = W \cdot \begin{bmatrix} B_1 \\ B_2 \\ B_3 \end{bmatrix} = (0, 0.155, 0.314, 0.295, 0.236)$$

The row vector C is formed from five evaluation grey clusters (Hu Shenghuang, 1996). This gives $C = (1, 2, 3, 3, 5)$. Using the results for B and C , we can finally evaluate the technology innovation risk (E) of the entire Chinese oil and gas industry.

$$E = B \cdot C^T = (0, 0.155, 0.314, 0.295, 0.236) \cdot \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{bmatrix} = 3.612$$

The value E indicates the overall risk level of technology innovation. To figure out the risk structure more explicitly, we evaluate the risk of each index belonging to hierarchy 2 in the same way. The results are E_1 , E_2 and E_3 for U_1 , U_2 and U_3 separately.

$$E_1 = B_1 \cdot C^T = (0, 0.152, 0.312, 0.298, 0.238) \cdot \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{bmatrix} = 3.631$$

$$E_2 = B_2 \cdot C^T = 3.592$$

$$E_3 = B_3 \cdot C^T = 3.618$$

4. EVALUATION RESULTS ANALYSIS

The evaluation shows that technology innovation in the Chinese oil and gas industry has several risks and uncertainties. In this evaluation, the technology innovation risk of Chinese oil and gas industry was determined to 3.612. Using a 5-rank system “very low ($h=1$), low ($h=2$), general ($h=3$), high ($h=4$) and very high ($h=5$),” the result is between “general” and “high” but somewhat closer to “high.” In other words, this implies that the associated risk for technology innovation in Chinese oil and gas industry is relatively high.

The result $E = 3.612$ represents the overall risk level for technology innovation. Fine structure analysis can also estimate the risk level for the subordinate indexes: technology risk is 3.631, management risk is 3.592 and external risk is 3.618. The risk is relatively high for all categories and fairly consistent. The technology risk is the highest, showing that many uncertainties impact technology innovation, especially when considering the relative immaturity of the Chinese technology innovation system. External risk is the second highest and this implies that changing market conditions, environmental and sociopolitical decisions can affect oil and gas technology innovation to a significant extent. For example, new energy policies or environmental laws may significantly influence the overall feasibility of certain technologies, even though the purely technical part works flawlessly. In comparison, management risk is the lowest in the three indexes, but the value is still relatively high.

Some general risk mitigation strategies should be implemented to reduce the relatively high technology innovation risk found in the Chinese oil and industry:

- (1) *Risk aversion*. This means staying clear of technology innovations with high associated risks.
- (2) *Risk control*. This features measures to reduce high risks and alleviate potential risk factors.
- (3) *Risk transferring*. This is the way to diversify the risk to other innovation items by effective management or decisions. It’s similar to asset allocation decisions in stock markets.

These three strategies have been proved successful in decreasing technology innovation risks and might be suitable for the Chinese situation. Using these principles, this paper gives some policy suggestions:

(1) Pay close attention to technology risks. These risks are closely related to technology innovation itself and are the most important factor (based on its height weight of 0.408). The level of technology in Chinese oil and gas industry is generally lower than for more developed countries, indicating that the technology innovation risk must likely be higher. Based on this point of view, more attention should be given to this category.

(2) It is necessary to strengthen the management ability to improve risk management. Management may be seen as a “*soft power*” but it is crucial for innovation. Technology management for Chinese oil and gas industry has improved significantly after many years of development, but still not enough to reduce the overall risk levels for innovation.

(3) Establishment of risk prevention systems. A risk prevention system may be defined as a set of efficient ways to protect innovation from risk. Such schemes can reduce risk exposure and ensure the success of technology innovation. At present, there is no system like this in the Chinese oil and gas industry and our analysis on internal and external risks indicate that such a framework should be formed.

To summarize, technology innovation in China’s oil and industry is manageable and in a controllable range. Overall risk levels have not yet reached the level of high ($h=4$) or very high ($h=5$) and this is not the case for the risks of the three secondary indexes either. However, it is imperative that measures are taken to prevent risks from increasing to higher levels. Low risks and proper risk management is essential for successful development of the growing Chinese oil and gas industry.

5. CONCLUSIONS

Using the multi-hierarchy grey method, we evaluated the technology innovation risk of the Chinese oil and gas industry. The risk is estimated to 3.612 on a scale ranging from 1 to 5, which can be seen as relatively high. In addition, evaluation results for technology risk, management risk and external risk were assessed to 3.631, 3.592, and 3.618 respectively. These results imply that China's oil and gas industry has relatively high technology innovation risk. Consequently, it is advisable to minimize risk exposure and take proper measures for proper risk management in the future.

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FIGURES

Figure 1 Evaluation process of multi-hierarchy grey method

Figure 2 Five definite weighted functions