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Credit Risk Evaluation of Online Supply Chain Finance Based on Third-party B2B E-commerce Platform: an Exploratory Research Based on China's Practice

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Abstract

With reference to the characteristics of online supply chain finance, this paper establishes a credit rating index system for the loan enterprise in the online supply chain finance that is based on the third-party B2B e-commerce platform. The system applies the multi-level gray evaluation model based on the Theil index to make a comprehensive evaluation on the credit of the loan enterprise and tests the model's feasibility through the analyses of numerical example. The evaluation model overcomes the subjectivity of weight distribution to index and presents the degree (from excellent to poor) of indices on each hierarchy distinctly so as to enable banks to take risk control specifically in operation.

Keywords*: B2B, online supply chain finance, credit risk evaluation, theil index, multi-level gray evaluation model*

1. Introduction

In recent years, commercial banks in China all launch online supply chain finance service, which not only solves the problem of convenience and timeliness of SMEs financing but also raises the supply chain collaboration to a new height. In the meantime, while the big data pushes the reform of management to move forward, new cooperation models emerge in an endless stream and online supply chain finance services based on third-party B2B e-commerce platform such as the "e-Dan Tong" short-term financing service put up forward by CCB (China Construction Bank), JYD O2O commodity e-commerce platform and Cosco Logistics arouse concerns inside the industry. In such cooperation model, the bank takes full advantage of data accumulated in the third-party B2B e-commerce platform to implement line of credit and dynamic monitoring over SMEs, which provides new solution for the information asymmetry problem that has long troubled supply chain finance service. Some time in the future the online supply chain finance service based on third-party B2B platform in China led by CCB will achieve a rapid development and more commercial banks will expand their services into this field. At the same time, we find that, there have been a lot of changes in risks that the banks face under the new model. Therefore, studying the credit risk management of this new model is of great significance to the banks. In this paper, we attempt to find a method of credit risk management that would be suitable.

The literature on the study of online supply chain finance based on B2B started early. Cronin (1997) proposed in his Banking and Finance on the Internet that the scientific and technological development would accelerate the infiltration of e-commerce that would become an important branch of financial services [1]. Heng (2001) made analysis of the reciprocal effect between e-commerce and financial system from three perspectives. He believed that the rapid development of e-commerce would be bound to bring innovative

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products and commercial opportunities for services to the bank, and the financing activities based on e-commerce platform were feasible [2]. Corning (2001) put that B2B e-commerce activities would provide convenience for developing immediate financing so that e-businessman could ally with financial organizations like banks to develop new services such as credit management, financing and dispute settlement [3].

Compared with study abroad, China started up late in this area. However, many scholars researched the supply chain financing models, which were based on B2B, which fit in the current state of China on the basis of some typical cases. They also made deep analyses of advantages and existing risks of the model. Li Mingrui (2007) put up forward that it would improve the state of SMEs financing in China if we could develop supply chain financing activities through the third-party e-commerce platform [4]. Zhang Qiang (2007) firstly raised the electronic warehouse receipt, which would achieve the integration of e-commerce and "pledge by warehouse receipts". He also analyzed the reason, operation and benefits of that model [5]. Wu Qiang (2011) explored problems in online supply chain finance based on third-party B2B e-commerce platform and pointed out the construction of comprehensive supporting mechanism should be accelerated [6]. Li Weijiao (2011) set out from the analysis of online supply chain finance models which were based on third-party B2B platform and arrived at the conclusion that these new models would effectively reduce the bank's credit risks brought by financing to the SMEs [7]. Tao Qiang (2012) made a preliminary analysis of logistics financing model that was based on third-party B2B e-commerce platform and then established a risk index system to deliver a comprehensive evaluation of risks that banks would face [8]. He Juan (2010) put up forward the concept of "cloud warehousing", an innovative supply chain financing service, and she introduced its operation mode [9]. Guo Jue, Shi Jinzhao, et al. (2014) made a deep analysis of evolution and risk elements of online supply chain finance models that were based on third-party B2B by theoretical study and comparative study. They found that although online supply chain finance had improved a lot in collaborative operation and service efficiency, because of the characteristics of e-business and online operation, the risks that banks were confronted with increased on the whole. According such situation, the author proposed some suggestions for banks' risk control from different perspectives [10].

As it has been mentioned above, in China the study of online supply chain finance based on third-party B2B platform is still at an early stage. Scholars mainly concentrate on the summarization and analysis of its conception and models and do little in the study of risk control. Among the various risks that banks face, risks such as operational risks, market risks and legal risks can be controlled by means of process design and contact items. However, the precaution of credit risks still remains as a key point as well as challenge in risk control for banks. Therefore, this paper will aim at the credit risk evaluation of online supply chain finance and develop researches, including the choice of evaluation methods, the establishment of the index system, the evaluation process and analyses of numerical example.

2. Evaluation Methods and the Choice of Index

2.1. Choice of Evaluation Methods

The management methods of credit risks for commercial banks mainly include rating methods, grading methods and expert system [11]. In practice, the widely used crediting rating methods include financial rate analysis, Logit model, fuzzy comprehensive evaluation, gray theory evaluation method, KMV model, Credit Metrics model and so on. The credit risk evaluation of online supply chain finance needs to take various quantitative and qualitative indices into consideration such as corporations' financial

credit, electronic credit and the stability of the supply chain. In addition to that, due to the deficiency in credit database of SMEs in China and irregularity of financial data in SMEs, many evaluation models cannot apply to the situation in China. With the studies over practices in China, we can conclude that credit rating of online supply chain finance is a typical grey problem thus a correspondingly grey evaluation model will be suitable for that.

2.2. Choice of Indices

Many scholars have carried on studies over the choice of indices for SMEs credit rating. Yang Xiongsheng and Yang Zhendai (1998) summarized corporations' comprehensive indices of various organizations such as the Ministry of Finance of PRC, National Bureau of Statics, National Committee for Economic System Reform and the Chinese Corporation Evaluation Center of the Management World. Then through the Delphi method, they established twelve widely accepted indices [12]. Fan Bonai and Zhu Wenbin (2003) delivered theory selection and empirical study over SMEs credit rating indices. Through the subordination analysis, correlation analysis and discrimination analysis, they selected fifteen SMEs credit rating indices, comprising a comprehensive evaluation covering various abilities of SMEs such as solvency, operation, innovation, profitability and development [13]. Yan Junhong (2007) introduced the SMEs credit rating indices into the credit risk evaluation of supply chain finance. He further established a set of credit risk evaluation index system of SMEs supply chain finance on the basis of the characteristics of supply chain finance [12]. Based on the credit rating of supply chain finance indices put up forward by Yan Junhong and combined with new characteristics of online supply chain finance, this paper lists the credit record out as the second-class index and partly adjusts other indices so as to construct a credit risk index system of online supply chain finance based on third-party B2B platform as it is shown in Table1.

The index system consists of four levels: target level (target u, first-class index level ($u_i, i=1,2,3,4$), second-class index level ($u_{ij}, i=1,2,3,4;\ j=1,2,\cdots,n_i$), third-class index level (u_{ijk}, $i=1,2,3,4; j=1,2,\cdots,n_i; k=1,2,\cdots,n_{ij}$). Among them, n_i refers to the amount of indices in the inferior class of the index u_i and n_{ij} refers to the amount of indices in the inferior class of the index u_{ij}.

3. Credit Risk Evaluation Process of Online Supply Chain Finance

3.1. Determining Index Weight

While determining the weight of index, traditional Delphi method and AHP (analytic hierarchy process) relied too much on the subjective judgment of experts. To make the weighting more scientific, this paper evaluates the importance of different indices according to their discrimination ability. That is, if all the objects being evaluated scatter on a specific index or there is a huge gap between evaluation values, the discrimination degree of the index to the evaluated object is high, or the index has strong discrimination ability. This paper introduces the Theil index of inequality to measure the discrimination ability of indices. Henry Theil firstly proposed the Theil index. At first it was used to measure the degree of income inequality and was widely applied in studying issues like the inequality of income distribution and regional economic gap [14]. The weight of indices is measured as follows.

Table 1. Credit Risk Index System of Online Supply Chain Finance

Target level	First-class index level	Second-class index level	Third-class index level
Credit risk index system of online supply chain finance based on third-party B2B platform (u)	Industrial factors (u1)	Macro environment (u11)	Macroeconomic policy (u111) Industrial prospect (u112)
		Pledge property (u12)	Stability of pledge price (u121) Disposal channel (u122)
	Corporate strength (u2)	Enterprise basic quality (u21)	Enterprise scale (u211) Leaders' quality (u212) Management level (u213)
		Solvency (u22)	Asset-liability ratio (u221) Liquidity ratio (u222) Interest cover ratio (u223)
		Operation (u23)	Nventory turnover ratio (u231) Accounts receivable turnover ratio (u232) Current assets turnover ratio (u233)
		Profitability (u24)	Gross profit margin (u241) Return on assets (u242)
	Credit record (u3)	E-credit level (u31)	Online registration time (u311) Online transaction number of times (u312) Online transaction volume (u313) Online credit rate (u314) Customer evaluation (u315)
		Financial credit record (u32)	____
	Supply chain strength (u4)	Core enterprise strength (u41)	Industrial status of core enterprise (u411) Asset-liability ratio (u412) Gross profit margin (u413)
		Supply chain competitiveness (u42)	Competitiveness of product quality (u421) Consumer satisfaction of products (u422)
		Supply chain cooperation level (u43)	Sustainability of transaction (u431) Close cooperation of upstream and downstream (u432) Information sharing of upstream and downstream (u433)

Suppose that we carry on credit rating to n supply chain financing corporations. There are m indices as G_s ($s = 1, 2, \cdots, \mathrm{m}$) with evaluation value of them as g_{ts} ($t = 1, 2, \cdots, \mathrm{n}; \mathrm{s} = 1, 2, \cdots, \mathrm{m}$). The weight vectors of indices are $W_s = (\mathrm{W}_1, \mathrm{W}_2, \cdots, \mathrm{W}_m)$ with $W_s \geq 0$ ($s = 1, 2, \cdots, m$) and $\sum_{s=1}^{m} W_s = 1$. Here we need to notice that the evaluation values g_{ts} should be put under the same dimension.

The Theil index is introduced into the matrix of evaluation $(g_{ts})_{n\times m}$ as:

$$T_s = \frac{1}{n}\sum_{t=1}^{n}(\frac{g_{ts}}{\bar{g}_{ts}}\ln\frac{g_{ts}}{\bar{g}_{ts}}) \tag{1}$$

Where, $t = 1,2,\cdots,n; s = 1,2,\cdots,m$. After the transformation, the Theil index T_s of G_s is:

$$T_s = \ln n + \sum_{t=1}^{n}(\frac{g_{ts}}{\sum_{t=1}^{n} g_{ts}}\ln\frac{g_{ts}}{\sum_{t=1}^{n} g_{ts}}) \tag{2}$$

The weight coefficient of index G_s is defined as [14]:

$$W_s = \frac{T_s}{\sum_{s=1}^{m} T_s} \tag{3}$$

Taking the derivative of Equation (2), we get $\frac{\partial T_s}{\partial n} = \frac{1}{n} + n > 0$, T_s gets its minimum 0 when $n = 1$. In the evaluation, as $n > 1, T_s > 0$. Therefore, W_s in Equation (3) satisfies the condition that $W_s \geq 0$ ($s = 1,2,\cdots,m$) and $\sum_{s=1}^{m} W_s = 1$. In this way, the weight of indices on different levels will be settled from the bottom level (third-class index level) to the top level (first-class index level) respectively.

3.2. Evaluation Process

3.2.1. Determine the Grading Standards: When rating according to the grading standards, we consider human's maximum discrimination ability and score by $1,2,3,4,5$ (points) with the middle point between every two of them as $1.5,2.5,3.5,4.5$ (points).

3.2.2. Experts Grade and Construct the Sample Matrix of Grading: Suppose invite p experts to grade a SME with sequence of experts marked by y where $y = 1,2,3,\cdots,p$. The expert y grades the index u_{ijk} at d_{ijky}, then the grading matrix is as follows:

$$D = \begin{bmatrix} d_{1111} & d_{1112} & \cdots & d_{111p} \\ d_{1121} & d_{1122} & \cdots & d_{112p} \\ d_{1211} & d_{1212} & \cdots & d_{121p} \\ & & \vdots & \\ d_{2111} & d_{2112} & \cdots & d_{211p} \\ & & \vdots & \\ d_{4111} & d_{4112} & \cdots & d_{411p} \\ & & \vdots & \\ d_{4331} & d_{4332} & \cdots & d_{433p} \end{bmatrix} \begin{matrix} u_{111} \\ u_{112} \\ u_{121} \\ \vdots \\ u_{211} \\ \vdots \\ d_{411} \\ \vdots \\ d_{433} \end{matrix} = (\mathrm{d}_{ijky})_{(2+2+3+3+3+2+5+3+2+3)\times \mathrm{p}} \tag{4}$$

3.2.3. Determine the Evaluation Grey Classification: Experts give the whitened value of the grey number after grading. To reflect the degree to which the whitened value belongs to a specific class, we need to determine the evaluation grey classification. That is, to determine the numbers of the evaluation grey classification, the grey number of grey classification and the whitenization weight function [15].

Suppose there are h evaluation grey classes, numbered as $e, e = 1, 2, \cdots, \mathrm{h}$. This paper supposes the evaluation grey classes of the loan enterprise in the online supply chain finance are five as $h = 5$. These five classes are labelled as "excellent", "sub-excellent", "good", "relatively poor", and "poor", correspondingly grading by $5, 4, 3, 2, 1$. On the basis of that, we then determine the whitenization weight function and describe these grey classes (the threshold value of the function adopts the comparative value, which means to take the maximum and minimum value in the matrix as the upper and lower limit for the threshold).

For the first grey class "excellent" ($e = 1$), the grey number $\otimes_1 \in [0, 5, 10]$, the whitenization weight function is expressed as:

$$f_1(\mathrm{d}_{ijky}) = \begin{cases} \dfrac{d_{ijky}}{5} & d_{ijky} \in [0, 5] \\ 1 & d_{ijky} \in [5, 10] \\ 0 & d_{ijky} \notin [0, 10] \end{cases} \tag{5}$$

For the second grey class "sub-excellent" ($e = 2$), the grey number $\otimes_2 \in [0, 4, 8]$, the whitenization weight function is expressed as:

$$f_2(\mathrm{d}_{ijky}) = \begin{cases} \dfrac{d_{ijky}}{4} & d_{ijky} \in [0, 4] \\ \dfrac{8 - d_{ijky}}{4} & d_{ijky} \in [4, 8] \\ 0 & d_{ijky} \notin [0, 8] \end{cases} \tag{6}$$

For the third grey class "good" ($e = 3$), the grey number $\otimes_3 \in [0, 3, 6]$, the whitenization weight function is expressed as:

$$f_3(\mathrm{d}_{ijky}) = \begin{cases} \dfrac{d_{ijky}}{3} & d_{ijky} \in [0, 3] \\ \dfrac{6 - d_{ijky}}{3} & d_{ijky} \in [3, 6] \\ 0 & d_{ijky} \notin [0, 6] \end{cases} \tag{7}$$

For the fourth grey class "relatively poor" ($e = 4$), the grey number $\otimes_4 \in [0, 2, 4]$, the whitenization weight function is expressed as:

$$f_4(\mathrm{d}_{ijky}) = \begin{cases} \dfrac{d_{ijky}}{2} & d_{ijky} \in [0, 2] \\ \dfrac{4 - d_{ijky}}{2} & d_{ijky} \in [2, 4] \\ 0 & d_{ijky} \notin [0, 4] \end{cases} \tag{8}$$

For the fifth grey class "poor" ($e = 5$), the grey number $\otimes_5 \in [0, 1, 2]$, the whitenization weight function is expressed as:

$$f_5(\mathrm{d}_{ijky}) = \begin{cases} 1 & d_{ijky} \in [0,1] \\ 2 - d_{ijky} & d_{ijky} \in [1,2] \\ 1 & \\ 0 & d_{ijky} \notin [0,2] \end{cases} \tag{9}$$

3.2.4. Calculate the Grey Evaluation Coefficient: Define that the evaluation coefficient of the No.e class that index u_{ijk} belongs to is x_{ijke}, then:

$$x_{ijke} = \sum_{y=1}^{p} f_e(\mathrm{d}_{ijky}) \tag{10}$$

Define that the total evaluation coefficient of each grey class that index u_{ijk} belongs to is x_{ijk}, then:

$$x_{ijk} = \sum_{e=1}^{5} x_{ijke} \tag{11}$$

3.2.5. Calculate Grey Evaluation Weight Vector and the Weight Matrix: Define that for index u_{ijk}, the evaluator holds that the grey evaluation weight of the No.e grey class is r_{ijke}, then:

$$r_{ijke} = \frac{x_{ijke}}{x_{ijk}} \tag{12}$$

The evaluation weight vector of index u_{ijk} to each grey class is r_{ijk} (the grey classes are five as $h = 5$, or $e = 1, 2, \cdots, 5$), then:

$$r_{ijk} = \left(r_{ijk1}, r_{ijk2}, r_{ijk3}, r_{ijk4}, r_{ijk5} \right) \tag{13}$$

Then we can get the evaluation weight matrix R_{ij} of subordinate index u_{ijk} (of the index u_{ij}) to each grey class:

$$R_{ij} = \begin{bmatrix} r_{ij1} \\ r_{ij2} \\ \vdots \\ r_{ijn_{ij}} \end{bmatrix} = \begin{bmatrix} r_{ij11} & r_{ij12} & \cdots & r_{ij15} \\ r_{ij21} & r_{ij22} & \cdots & r_{ij25} \\ & & \vdots & \\ r_{ijn_{ij}1} & r_{ijn_{ij}2} & \cdots & r_{ijn_{ij}5} \end{bmatrix} \tag{14}$$

3.2.6 Determine the Weight of Indices in Each Level: To complete assignment of grey classes according to the grey level as the first class is assigned as d_1, the second class as d_2, $\cdots$, the No.h class as d_h. In this case, $h = 5, d_1 = 5, d_2 = 4, d_3 = 3, d_4 = 2, d_5 = 1$, the vector C as a value of each evaluation grey class is:

$$C = (5, 4, 3, 2, 1) \tag{15}$$

The evaluation value of index u_{ijk} of the evaluated corporation is g_{ijk}, then:

$$g_{ijk} = r_{ijk} \cdot C^T \tag{16}$$

g_{ijk} accords to g_{ts} in Equation (1). The weight of the third-class indices can be obtained after using the Equation (1)-(3), the weight of the second-class indices can be got after Equation (17) and the weight of the first class indices can be got after Equation (19) with similar methods: take the comprehensive evaluation value of a level of indices

(uniformization needed) and use Equation (1)-(3) to determine the weight distribution of indices at that level. Briefly speaking, the weight of indices at each level is given as follows:

Suppose that the weight distribution of the first-class index u_i is $a_i\left(i=1,2,3,4\right)$ (there are four first-class indices in this study), then the weight vector is $W=\left(a_1,a_2,a_3,a_4\right)$; the weight vector of the second-class index $u_{ij}\left(i=1,2,3,4;\ j=1,2,\cdots,n_i\right)$ is $W_i=\left(a_{i1},a_{i2},\cdots,a_{in_i}\right)$; the weight vector of the third-class index $u_{ijk}(i=1,2,3,4;\ j=1,2,\cdots,n_i;\mathrm{k}=\ 1,2,\cdots,n_{ij})$ is $W_{ij}=\left(a_{ij1},a_{ij2},\cdots,a_{ijn_{ij}}\right)$.

3.2.7. Make a Comprehensive Evaluation: The result of the comprehensive evaluation of u_{ij} is B_{ij}, then:

$$B_{ij}=W_{ij}\cdot R_{ij} \tag{17}$$

On the basis of B_{ij}, we construct the evaluation weight matrix R_i of subordinate index u_{ij} of the index u_i:

$$R_i=\begin{bmatrix}B_{i1}\\B_{i2}\\\vdots\\B_{in_i}\end{bmatrix} \tag{18}$$

The result of the comprehensive evaluation of u_i is B_i, then:

$$B_i=W_i\cdot R_i \tag{19}$$

On the basis of B_i, we construct the evaluation weight matrix R of subordinate index u_i of the index u :

$$R=\begin{bmatrix}B_1\\B_2\\\vdots\\B_4\end{bmatrix} \tag{20}$$

The result of the comprehensive evaluation of u is B, then:

$$B=W\cdot R \tag{21}$$

3.2.8 Uniformization and Sequence of the Evaluation: To make it convenient for inspection and decision making, the result of the evaluation needs to be further uniformized. As the vector C has been introduced in step 6, here we will not redefine. After uniformization, the evaluation value of the evaluated corporation is:

$$S=B\cdot C^T \tag{22}$$

If $S\in\left[4,5\right]$, the credit of that corporation belongs to “excellent”; if $S\in\left[3,4\right]$, the credit of that corporation belongs to “sub-excellent”; if $S\in\left[2,3\right]$, the credit of that corporation belongs to “good”; if $S\in\left[1,2\right]$, the credit of that corporation belongs to “relatively poor”; if $S\in\left[0,1\right]$, the credit of that corporation belongs to “poor”.

4. Analyses of Numerical Example

A bank receives the online supply chain financing application from three corporations. Five professionals from the credit department in charge of risk control then grade these three corporations according to the index system. The matrixes are $D^{(1)}, D^{(2)}, D^{(3)}$ as shown in Equation (23).

$$D^{(1)}=\begin{bmatrix}4.0&3.5&3.0&3.5&4.5\\3.0&4.5&5.0&3.5&4.0\\2.0&1.5&2.0&2.5&1.5\\2.5&3.0&3.0&2.5&2.5\\3.0&3.5&4.0&4.0&3.5\\2.0&1.5&2.0&2.0&3.0\\5.0&4.5&4.0&4.0&5.0\\2.0&2.0&1.5&2.0&2.0\\3.0&3.5&4.0&4.0&3.5\\2.0&2.5&3.0&3.0&3.0\\4.0&4.5&5.0&5.0&4.5\\3.0&3.5&3.5&3.5&4.0\\4.0&3.5&3.5&3.5&3.0\\4.0&4.0&3.5&4.0&4.0\\3.0&3.5&3.5&3.5&4.0\\1.5&1.5&1.5&1.5&1.5\\2.0&2.0&2.0&2.0&2.0\\3.0&3.0&3.0&3.0&3.0\\3.0&3.0&3.0&3.0&3.0\\5.0&5.0&5.0&5.0&5.0\\3.0&2.5&2.5&2.0&2.0\\2.0&1.5&2.0&2.0&2.5\\3.0&3.5&3.5&3.5&3.0\\1.0&1.5&1.5&1.0&1.5\\2.0&2.0&1.5&1.5&2.0\\4.0&4.0&4.5&4.0&4.5\\3.0&3.0&3.0&3.0&3.5\\4.0&3.5&3.5&3.5&3.5\end{bmatrix}\quad D^{(2)}=\begin{bmatrix}2.0&2.5&3.0&3.0&2.5\\3.0&3.0&2.5&2.5&3.0\\3.0&3.5&3.5&2.5&3.0\\4.0&3.0&3.5&3.5&3.0\\1.0&0.5&1.0&1.5&1.0\\3.0&3.0&3.5&3.0&2.5\\4.0&4.5&3.0&3.5&4.0\\3.0&3.5&3.0&3.5&3.5\\3.0&3.5&4.0&3.5&3.0\\3.0&3.0&3.5&4.0&3.5\\3.0&3.0&3.0&3.0&3.5\\2.0&2.5&2.5&3.0&3.0\\2.0&2.0&3.0&2.5&2.0\\4.0&3.0&3.5&3.5&3.5\\3.0&3.5&4.0&4.0&4.0\\3.0&3.0&3.0&3.0&3.0\\3.5&3.5&3.5&3.5&3.5\\3.0&3.0&3.0&3.0&3.0\\4.0&4.0&4.0&4.0&4.0\\4.0&4.0&4.0&4.0&4.0\\4.0&4.5&4.0&4.0&4.0\\3.5&3.5&3.5&3.0&3.0\\2.5&3.0&3.0&3.0&3.0\\3.0&3.0&3.0&3.0&3.5\\3.0&3.5&3.5&3.5&3.5\\3.0&3.5&3.0&3.0&2.5\\2.0&2.5&2.5&2.5&2.5\end{bmatrix}\quad D^{(3)}=\begin{bmatrix}3.0&2.5&2.5&2.0&2.5\\2.5&3.0&3.5&3.5&3.0\\2.0&2.0&1.5&2.0&2.5\\2.0&2.0&1.5&2.5&2.0\\3.0&3.5&3.0&3.0&3.5\\4.0&4.5&4.0&2.5&4.0\\2.0&2.5&3.0&3.0&2.5\\3.5&3.5&3.5&4.0&3.5\\2.0&2.5&2.5&3.0&2.0\\3.0&3.5&3.0&3.0&3.5\\2.5&3.0&2.5&2.5&2.5\\1.5&1.0&1.0&2.0&1.5\\2.0&2.5&2.0&2.0&2.5\\3.0&3.5&3.5&3.0&3.0\\4.0&4.0&3.5&4.0&3.5\\4.0&4.0&4.0&4.0&4.0\\3.5&3.5&3.5&3.5&3.5\\2.0&2.0&2.0&2.0&2.0\\4.0&4.0&4.0&4.0&4.0\\3.5&3.5&3.5&3.5&3.5\\4.0&4.5&4.5&5.0&5.0\\2.5&2.5&3.0&3.0&3.5\\3.0&3.0&3.5&3.5&3.5\\3.0&3.5&3.5&3.0&3.0\\3.5&3.0&3.0&3.0&3.5\\2.0&2.5&2.5&2.5&2.0\\2.0&2.0&2.0&2.0&2.5\\2.5&2.5&3.0&3.0&3.0\end{bmatrix}\tag{23}$$

As u_{32} does not have a third-class index, its grading is listed out: $D_{u_{32}}^{(1)}=\begin{bmatrix}5&5&5&5&5\end{bmatrix}$; $D_{u_{32}}^{(2)}=\begin{bmatrix}5&5&5&5&5\end{bmatrix}$; $D_{u_{32}}^{(3)}=\begin{bmatrix}5&5&5&5&5\end{bmatrix}$.

With the method introduced in this paper (the details of calculation is omitted due to the limited length), the evaluation values of the three corporations are ranked as: $S^{(3)}>S^{(2)}>S^{(1)}$, and $S^{(3)}=3.024\in$ "sub-excellent"; $S^{(2)}=2.789\in$ "good"; $S^{(1)}=2.695\in$"good". Therefore, the bank will consider giving the loan in the sequence as: corporation 3, corporation 2, and corporation 1.

Through multi-level evaluation, we can get the comprehensive evaluation value of indices on different levels as in Table 2. On the basis of the evaluation value of indices, banks can focus on the index with high risk thus to pay more attention and mainly control in practice. In the following table, we take corporation 3 with the highest target comprehensive evaluation value as an example.

Table 2. The Summary Sheet of Evaluation Value on Different Levels of Corporation 3

Index u	Evaluation value	Index u_i	Evaluation value	Index u_{ij}	Evaluation value	Index u_{ijk}	Evaluation value
u	3.024 (sub-excellent)	u_1	3.224 (sub-excellent)	u_{11}	3.429 (sub-excellent)	u_{111}	3.323 (sub-excellent)
						u_{112}	3.570 (sub-excellent)
				u_{12}	3.078 (sub-excellent)	u_{121}	3.078 (sub-excellent)
						u_{122}	3.078 (sub-excellent

					)
u_2	3.363 (sub-excellent)	u_{21}	3.617 (sub-excellent)	u_{211}	3.606 (sub-excellent)
				u_{212}	3.917 (sub-excellent)
				u_{213}	3.362 (sub-excellent)
		u_{22}	3.651 (sub-excellent)	u_{221}	3.817 (sub-excellent)
				u_{222}	3.284 (sub-excellent)
				u_{223}	3.606 (sub-excellent)
		u_{23}	2.865 (sub-excellent)	u_{231}	3.362 (sub-excellent)
				u_{232}	2.587 (good)
				u_{233}	3.202 (sub-excellent)
		u_{24}	3.658 (sub-excellent)	u_{241}	3.606 (sub-excellent)
				u_{242}	3.932 (sub-excellent)
u_3	3.925 (sub-excellent)	u_{31}	3.925 (sub-excellent)	u_{311}	4.054 (excellent)
				u_{312}	3.762 (sub-excellent)
				u_{313}	3.117 (sub-excellent)
				u_{314}	4.054 (excellent)
				u_{315}	3.762 (sub-excellent)
		u_{32}	4.320 (excellent)	——	——
u_4	3.637 (sub-excellent)	u_{41}	3.970 (sub-excellent)	u_{411}	4.203 (excellent)
				u_{412}	3.485 (sub-excellent)
				u_{413}	3.656 (sub-excellent)
		u_{42}	3.606 (sub-excellent)	u_{421}	3.606 (sub-excellent)
				u_{422}	3.606 (sub-excellent)
		u_{43}	3.289 (sub-excellent)	u_{431}	3.243 (sub-excellent)
				u_{432}	3.160 (sub-excellent)
				u_{433}	3.437 (sub-excellent)

It can be seen from Table 2 that indices u_{311}, u_{314}, u_{411} of corporation 3 belong to the "excellent" grey class. The three indices respectively accord with "online registration time", "online credit rate" and "industrial status of core enterprise", which indicates these

three indices are the "safety indices" for the corporation. Index u_{232} belongs to the "good" grey class, and is the lowest among all indices, which indicates that "accounts receivable turnover ratio" is the "risky index" for the corporation. Therefore, the bank should pay attention to the monitoring and precaution of that index after deciding to give loan to corporation 3.

5. Conclusions

Based on China's practice, in this paper, we give a thorough analysis on the credit risk evaluation of online supply chain finance based on third-party B2B e-commerce platform. Three are three main contributions of our research: (1) With reference to the characteristics of online supply chain finance, we establish a credit rating index system for the loan enterprise in the online supply chain finance that is based on the third-party B2B e-commerce platform. (2) Apply the multi-level gray evaluation model based on the Theil index to make a comprehensive evaluation on the credit of the loan enterprise. (3) Test the model's feasibility through the analyses of numerical example.

Meanwhile, the proposed evaluation model has some typical advantages as follows: (1) Overcomes the subjectivity of weigh distribution to indices. (2) Presents the degree (from excellent to poor) of indices on each hierarchy distinctly so as to enable banks to take risk control specifically in operation. (3) The efficiency of the evaluation model can be easily enhanced through algorithm design, and the practical application value of the model is high.

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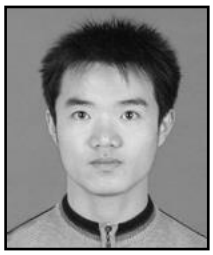

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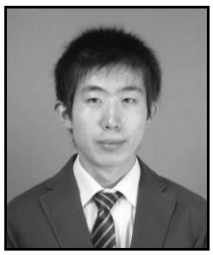

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