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A RISK PRE-WARNING MECHANISM OF CHINESE HIGH-TECH INDUSTRIES BASED ON INTERNATIONAL INTELLECTUAL PROPERTY BARRIERS

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Abstract. *The intellectual property barrier performed by developed countries has a severe impact on the survival and sustainable development of China's high-tech industries. In this paper, we firstly present a theoretical model of the space-time range of international intellectual property barrier on China's high-tech industries, that is, a three-dimensional risk pre-warning mechanism consisting of Technology (layout safety), Market (organization safety) and Policy (policy safety). Then, we combine fuzzy evaluation method and membership conversion algorithm to identify the risk of international intellectual property barrier on the safety of China's high-tech industries. Taking the LED (Light-Emitting Diode) industry for example, this paper judges the safety level of China's high-tech industries as the "normal" level. Industry layout safety and organization safety are observed as two main aspects impacting the safety of China's high-tech industries. Corresponding industry development suggestions are also discussed, such as enhancing the industry association service and building supporting government platforms.*
Keywords: Risk pre-warning mechanism, Industry safety, International intellectual property barrier, Membership conversion algorithm

1. Introduction.

Industrial safety refers to that the survival and development of a specific industry in a country or region is not threatened or threatened but with corresponding solutions [1,2]. In the new round of technological revolution and industrial revolution, multinational corporations and governments in developed countries take the intellectual property as an important strategic resource, and take various measures based on intellectual property protection to impede the free development of international trade [3,4]. They often use the technology monopoly strategy to consolidate and expand their market advantages and then build a new form of non-tariff trade barriers, that is, the intellectual property trade barriers. Its essence is in the name of protecting intellectual property rights to impede enterprises in developing countries to expand domestic and international markets, further maintaining its ability obtained through intellectual property rights. The control of companies in developed countries on core intellectual property rights has become an important factor impacting the industrial economic growth and industrial development safety in developing countries [5], which may be also one of the reasons why developing countries fall into the trap of middle income [6]. It is particularly important to note that once the intellectual property trade barrier is established, its monopoly and competitive advantages are difficult to break in the short term [7].

Since China fell behind in the industrial revolution and modern information revolution, technology application was the main way to follow modern science and technology

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in China. As a result, the majority of latest techniques are owned by a small number of developed countries [8]. Thus, the lack of core independent intellectual property rights is the most important problem of China's innovation-driven development [9,10]. International intellectual property barriers will fundamentally shake the foundation of China's high-tech industries [11,12]. The loss of industrial innovation and development capacity will seriously weaken the competitiveness of China's high-tech industries and maintain the disadvantaged position of China's high-tech industries in the international division of labor, finally affecting the survival and sustainable development of China's high-tech industries. Therefore, it is of great significance to recognize the risk of international intellectual property barriers faced by China's high-tech industries and establish a pre-warning mechanism to help the government formulate industrial policies and safeguard the safety of China's high-tech industries, thus in favor of coordinating the economic development and safeguarding the national interests. LED (Light-Emitting Diode) industry as a strategic emerging industry plays a significant role in improving industrial economic structure and energy consumption ways, so we take the LED industry as an example to specify our study. There are two main motivations for us to make this work. First, we want to construct an evaluation framework and index system for identifying the safety level of high-tech industry from the review of intellectual property barriers. Second, we want to present a membership conversion algorithm for deleting the redundant information in the evaluation data. To sum up, the following contributions are made in this work.

(1) From the perspectives of Technology (layout safety), Market (organization safety), and Policy (policy safety), we set up a space-time range model based on the international intellectual property barriers faced by China's high-tech industries, and build an evaluation index system of China's high-tech industry safety.

(2) We present a membership conversion algorithm which can dig the knowledge information hidden in the membership degree of each index and clarify the relationship between the classification target and the membership degree of each index.

(3) We apply the membership conversion algorithm into the evaluation of the safety of 2015 China's LED industry, and recognize the safety level of the whole industry and its criteria indexes. Meanwhile, we present practical observations and suggestions for China's LED industry.

The remainder of the work is organized as follows. Section 2 presents a brief review on related works. In Section 3, we present a space-time range model based on the international intellectual property barriers faced by China's high-tech industries and build an evaluation index system of China's high-tech industry safety. A fuzzy evaluation method of China's high-tech industry safety is given in Section 4. Section 5 presents evaluation results on the safety of 2015 China's LED industry and some observations based on the evaluation results. In Section 6, we conclude the work with some future directions.

2. **Literature Review.**

In this section, we mainly review a part of current related studies on industry safety and intellectual property barrier.

(1) Related studies on industry safety

At present, scholars have made studies on the industry safety problem involving various industries. Pinto [13] presented a qualitative occupational safety risk assessment model for the construction industry where the fuzzy sets theory is used to formulate the information elicitation into linguistic variables. Ifinedo [14] took the global financial services institutions as the samples to analyze the information security threats and controls in financial services industry, which concluded some preliminary findings for the practitioners. Zhao and Liu [15] reviewed the advances in the development of China's bioenergy industry, and concluded that the bioenergy is an effective resource to deal with China's energy security.

Lambrechts and Blomquist [16] analyzed the importance of political-security risk in the oil and gas industry. Yin et al. [17] argued that the investment in the accommodation industry is an important issue when constructing the Silk Road Economic Belt and the 21st-Century Maritime Silk Road (B&R), and presented an index system to evaluate the investment safety in the accommodation industry using relevant data on 24 B&R countries. As we can see, the safety issue has attracted more and more attention in many industries such as construction, financial services and bioenergy. The common idea to study the industry safety is to first construct a suitable evaluation index system for one specific industry and then evaluate the industry safety level using multiple attributive decision making methods. However, few studies are concerned with the analysis of the high-tech industry from the view of international intellectual property barriers. In this work, we try to fill the gap in the literature.

(2) Related studies on intellectual property barrier

Developed countries believe that the lack of intellectual property protection and intellectual property infringement cause obstacles to normal trades and then constitute trade barriers, but developing countries argue that the level of intellectual property protection is too high and the abuse of intellectual property rights constitutes barriers to normal trades [3,4]. The current literature shows that foreign scholars rarely use intellectual property as a trade barrier to carry out specialized research. The relevant research mainly focuses on the impact of intellectual property on trade. Maskus and Penubarti [18] analyzed the impact of intellectual property protection on goods trade from the market expansion effects and market force effects of intellectual property protection on trade. Smith [19] argued that strengthening intellectual property protection does not necessarily lead to monopolies due to the high imitation costs in developing countries' markets, making the impact of intellectual property on trade more difficult to determine. Ivus [20] used US export data from 1990 to 2000 to observe the impact of the strengthening of intellectual property rights on the exports of patent-sensitive products and found that the patent protection is an important factor impacting on whether US firms introduce new products into developing countries. Palangkaraya et al. [21] presented new measures of how patent affects trade, and found that the presence of destination-country blocking patents has more negative impact on trade than that of origin-country. Wu et al. [8] used the data of 80 countries from 1981 to 2010 to observe the impact of high-tech related export and inward foreign direct investment on national innovative capacity. As we can see, the intellectual property has been observed to have obvious impact on the international trade. Developed countries basically think it is reasonable to constitute trade barriers in order to protect intellectual property rights, but developing countries do not agree with the standpoint. However, few studies are concerned with how to identify risks resulted from the trade barriers and make an evaluation on the industry safety from the view of intellectual property barriers.

In general, Chinese domestic scholars focus on the study of intellectual property barriers from the perspective of the manifestation of intellectual property barriers and the macro analysis of trade influence or the micro-research perspective on enterprise export prevention. The existing research has vacancies in theory and practice, especially on industrial safety concerns in the industry level. Through the establishment of an efficient and dynamic industry safety evaluation system, this paper strengthens the risk monitoring of international intellectual property rights, which is helpful to timely detect hidden dangers, and as soon as possible to find appropriate feasible ways to control and manage high-tech industry security issues. However, in the risk evaluation process of high-tech industries, decision-makers have to consider multiple factors which include some qualitative indicators. When facing qualitative evaluations, people often have decision preferences which can be well represented by fuzzy numbers. Thus, this paper, from the perspective of meso level and development, introduces the theory of fuzzy evaluation into the industry safety evaluation of international intellectual property barrier risks.

3. Theoretical Model and Evaluation Index System.

3.1. Theoretical model. In this paper, we establish a three-dimensional risk pre-warning system consisting of Technology (layout safety), Market (organization safety), and Policy (policy safety). The Technology dimension reflects the inner driving force for the development of high-tech industry, mainly involving the capacity of competitiveness, innovation and control; the Market dimension reflects the market extroversion, concentration and control of high-tech industry; the Policy dimension reflects the policy environment of high-tech industry at home and abroad. From the perspective of strategic management, this institutional framework has set up a space-time range model based on the international intellectual property barriers faced by China's high-tech industries, as Figure 1 shows. The bigger the space-time range is, the bigger the threat for China's industry safety is. The industry safety warning response levels include "safe", "basically safe", "normal", "unsafe", and "dangerous". The above research framework provides a clear framework for the establishment of a pre-warning mechanism of intellectual property barriers.

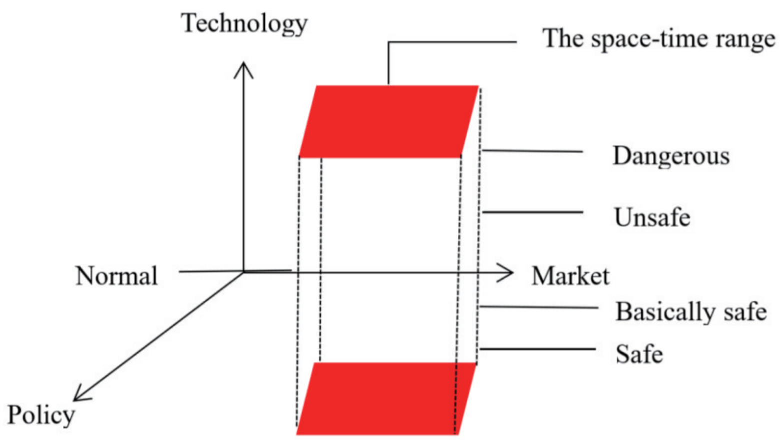

FIGURE 1. A space-time range model based on the international intellectual property barriers

3.2. The evaluation index system of China's high-tech industry safety. On the basis of the above theoretical framework, this section presents an evaluation index system of high-tech industry safety based on international intellectual property barriers. We invite 40 experts to evaluate the index system based on 40 LED export enterprises and use AHP (Analytic Hierarchy Process) to determine the weight of each index in the system. The original evaluation results are shown in Table 1 where the five levels are denoted by D_1 (Safe), D_2 (Basically safe), D_3 (Normal), D_4 (Unsafe), and D_5 (Dangerous). The detailed explanations on these indexes are as follows.

(1) The "Technology" indexes

As mentioned above, the "Technology" dimension refers to the layout safety (A_1). This criterion layer consists of three sub-criterion layers: technological competitiveness (B_{11}), sustainable innovation (B_{12}), and IP (Intellectual Property) control (B_{13}) [5-7,22].

a) Technological competitiveness layer

This layer has four specific indexes: the number of domestic patent licensing by China LED enterprises (C_{111}), the number of patent authorization by China LED enterprises

(C_{112}), the matching degree of LED enterprises' IP dependability and IP capacity (C_{113}), and the age proportion of authorized patents maintained by LED enterprises (C_{114}).

Both C_{111} and C_{112} indexes are objective. More patent licensing and patent authorization by China LED enterprises indicate that the stronger the technological innovation capability is, the more secure Chinese LED industry is. C_{113} index is a subjective index. The higher the matching degree is, the more intellectual property rights LED enterprises own, so the safer Chinese LED industry is. C_{114} index is an objective index. The longer LED enterprises maintain patent licenses, the higher value these patents have, so the safer Chinese LED industry is. The maintenance age is divided into five categories: 13 years or more (safe), 10 to 12 years (basically safe), 7 to 9 years (normal), 4 to 6 years (unsafe), and 1 to 3 years (dangerous).

b) Sustainable innovation layer

This layer has four specific indexes: the R&D (Research and Development) investment ratio of LED enterprises (C_{121}), the stage of technological innovation (C_{122}), the degree of close cooperation between LED enterprises and LED-related research institutions (C_{123}), and the role of IP management department in technological innovation (C_{124}).

C_{121} index is an objective index, which is calculated by:

$$C_{121} = \frac{\text{Total R\&D investment}}{\text{Total sales revenue}} \times 100\% \tag{1}$$

As we know, the higher total R&D investment is, the stronger LED industry's continuous innovation capability is, so the safer Chinese LED industry is. The index level is: 7% or more (safe), 5 to 7% (basically safe), 3 to 5% (normal), 1 to 3% (unsafe), and 1% or below (dangerous).

C_{122} index is also objective. The source of technological innovation can be divided into five stages: simple imitation, technology purchase, technology improvement, production and research cooperation innovation, and the latter three combination. LED enterprises in later stages often have stronger ability of integrating technology innovation resources, which is more helpful to continuous innovations in LED industry and makes China's LED industry more secure.

Both C_{123} and C_{124} are subjective. The closer the cooperation degree between LED enterprises and LED-related research institutions is, the safer Chinese LED industry is. The greater role in the technological innovation IP management department plays, the more conducive to mobilize enterprise resources to carry out technological innovation, so the safer Chinese LED industry is.

c) IP control layer

This layer has four specific indexes: the patent layout of LED enterprises (C_{131}), the patent pool and patent alliance established or joined by LED enterprises (C_{132}), the patent standardization of Chinese LED industry (C_{133}), and the control rate of foreign-funded patents in Chinese LED industry (C_{134}).

The former three indexes, that is, C_{131}, C_{132} and C_{133}, are subjective. Better patent layout is more conducive to help LED enterprises accomplish patent defense, protection and maintenance of market position, better patent pool and patent alliance indicates that LED enterprises have stronger ability of patent operations, and higher standardization degree means the more likely to achieve the largest economic benefits of patent value. Thus, the bigger these three index values are, the safer Chinese LED industry is.

C_{134} index is an objective and contrary index, which is calculated by:

$$C_{134} = \frac{\text{The number of patents licensed to foreign-funded LED enterprises}}{\text{The number of patents licensed to Chinese LED industry}} \tag{2}$$

Higher control rate of foreign-funded patents in Chinese LED industry indicates foreign investment may strengthen technology monopoly and technology transfer restrictions to the LED industry, so the more unsafe Chinese LED industry is.

(2) The "Market" indexes

The "Market" dimension refers to the organization safety (A_2). This criterion layer consists of three sub-criterion layers: extroversion level (B_{21}), market concentration (B_{22}), and market control (B_{23}) [4,5,8,14]. The detailed indexes included in these layers are as follows.

a) Extroversion level layer

This layer has three specific indexes: export dependency (C_{211}), import dependency (C_{212}), and the trade competitiveness index in LED industry (C_{213}).

C_{211} index is an objective and contrary index, which is calculated by:

$$C_{211} = \frac{\text{The exports of Chinese LED products and raw materials}}{\text{The output value of Chinese LED industry}} \times 100\% \tag{3}$$

Higher export dependence indicates the industry safety is more heavily impacted by international factors, so the more unsafe Chinese LED industry is.

C_{212} index is also an objective and contrary index, which is calculated by:

$$C_{212} = \frac{\text{The imports of Chinese LED products and raw materials}}{\text{The output value of Chinese LED industry}} \times 100\% \tag{4}$$

Similarly, higher import dependence also indicates the industry safety is more heavily impacted by international factors, so the more unsafe Chinese LED industry is.

The trade competitiveness index in LED industry, that is, C_{213}, is an objective index which is calculated by:

$$C_{213} = \frac{\text{LED exports} - \text{LED imports}}{\text{LED exports} + \text{LED imports}} \tag{5}$$

The higher the index is, the safer Chinese LED industry is.

b) Market concentration layer

This layer has two specific indexes: the aggregation degree of Chinese LED industry in the international LED industry (C_{221}) and the market concentration of Chinese LED industry (C_{222}).

C_{221} index is a subjective index. Higher aggregation degree indicates Chinese LED industry has a stronger international competitiveness, so the safer Chinese LED industry is. C_{222} index is an objective index, which is calculated by:

$$C_{222} = 1000 \times \sum_{i=1}^{20} \left(\frac{CP_i}{TPV} \right)^2 \tag{6}$$

where CP_i denotes the output value of the ith top 20 Chinese LED enterprise, and TPV denotes the total output value of 2015 Chinese LED industry. Higher market concentration indicates that a single LED enterprise has increased market share which correspondingly enhances its development capacity and international competitiveness, so the safer Chinese LED industry is.

c) Market control layer

This layer has three specific indexes: the world market share of China LED products (C_{231}), the control of foreign-funded enterprises in China LED market (C_{232}), and the brand competitiveness of China LED product (C_{233}).

C_{231} index is an objective index, which is calculated by:

$$C_{231} = \frac{\text{The output value of Chinese LED lighting industry}}{\text{The output value of world LED lighting industry}} \times 100\% \tag{7}$$

Bigger C_{231} indicates China's LED products have higher market share in the world, so the safer Chinese LED industry is.

Both C_{232} and C_{233} are subjective. The stronger the control of foreign-funded enterprises in China LED market is, the greater the share of foreign investment in China's LED market is, so the more unsafe Chinese LED industry is. The stronger the brand competitiveness is, the safer Chinese LED industry is.

(3) The "Policy" indexes

The "Policy" dimension refers to the policy safety (A_3). This criterion layer consists of two sub-criterion layers: the effectiveness of domestic industrial policy (B_{31}) and the threat of international industry policy (B_{32}) [3,5,20]. The detailed indexes included in these layers are as follows.

a) The effectiveness of domestic industrial policy

This layer has three specific indexes: the contribution of China technological innovation encouragement policies to the increase of LED industry output value (C_{311}), the contribution of China export promotion policies to the increase of LED industry output value (C_{312}), and the contribution of other industry support policies to the increase of LED industry output value (C_{313}). The bigger these three policy indexes are, the more beneficial to LED industry safety domestic industrial policies are. Other industry support policies include talent policy, tax preferential policy, land policy, capital investment policy, investment policy and so on.

b) The threat of international industry policy

This layer has three specific indexes: the impact of international technical trade barriers on LED product export (C_{321}), the impact of import control restrictions on LED product export (C_{322}), and the impact of intellectual property barrier on LED product export (C_{323}). The bigger these three policy indexes are, the bigger threat to LED industry safety international industry policy has.

In Table 1, the value in the bracket following each index is the weight of the index which is determined by AHP (Analytic Hierarchy Process). Due to the limitation of space, we do not give the detailed process of using AHP to determine the weights. Actually, our proposed method can deal with situations with different weight settings. The vector after the underlying index in Table 1 is the membership degree vector of the five ratings: safe, basically safe, normal, unsafe, and dangerous. For the objective indexes, we show the details of obtaining the original data in Section 5; for the subjective indexes, we use the expert scoring method which is one widely accepted method for determining the fuzzy membership of subjective indexes.

4. **The Fuzzy Evaluation on the Risk of International Intellectual Property Trade Barriers Faced by China's High-Tech Industries.** In many real-world situations, fuzzy and uncertain information is often involved [23-25]. Similarly, when we determine the original evaluation data for the evaluation index system in Table 1, it is often not easy to obtain crisp data due to the uncertainty in the real world, especially for the subjective indexes. In this work, we use 40 experts to evaluate the subjective indexes, but these experts may rate the industry safety into different levels. For example, for C_{113} in Table 1, the rating on the five levels is 1, 15, 18, 5 and 1. In this situation, we have to use fuzzy techniques to represent the evaluation result. In Liu et al.'s work [26], they presented an entropy-based data mining method to dig the knowledge information hidden in the membership degree of each index and clarify the relationship between the classification target and the membership degree of each index. In the method, they define index discrimination value to eliminate the redundant information in membership degrees for the target classification and extract effective values to calculate the target membership.

TABLE 1. The evaluation index system and original evaluation data

The goal	**The criterion layer**	**The sub-criterion layer**	**The index layer**	D_1	D_2	D_3	D_4	D_5
G: The fuzzy evaluation on the risk of international intellectual property trade barriers faced by China's high-tech industries	A_1: Layout safety (0.29935)	B_{11}: Technological competitiveness (0.32634)	C_{111}: The number of domestic patent licensing by China LED enterprises (0.36431)	0	1	0	0	0
			C_{112}: The number of patent authorization by China LED enterprises (0.23190)	0	0	0	1	0
			C_{113}: The matching degree of LED enterprises' IP dependability and IP capacity (0.18737)	1	15	18	5	1
			C_{114}: The age proportion of authorized patents maintained by LED enterprises (0.21641)	6	12	8	8	6
		B_{12}: Sustainable innovation (0.41457)	C_{121}: The R&D investment ratio of LED enterprises (0.2777)	2	6	16	14	2
			C_{122}: The stage of technological innovation (0.26560)	6	9	14	5	6
			C_{123}: The degree of close cooperation between LED enterprises and LED-related research institutions (0.23906)	2	11	15	9	3
			C_{124}: The role of IP management department in technological innovation (0.20757)	2	16	16	5	1
		B_{13}: IP control (0.25909)	C_{131}: The patent layout of LED enterprises (0.25433)	2	18	14	6	0
			C_{132}: The patent pool and patent alliance established or joined by LED enterprises (0.20290)	2	11	18	4	5
			C_{133}: The patent standardization of Chinese LED industry (0.24008)	2	3	23	11	1
			C_{134}: The control rate of foreign-funded patents in Chinese LED industry (0.30270)	0	0	0	1	0
	A_2: Organization safety (0.30980)	B_{21}: Extroversion level (0.34407)	C_{211}: Export dependency (0.37328)	0	1	0	0	0
			C_{212}: Import dependency (0.30569)	0	1	0	0	0
			C_{213}: The trade competitiveness index in LED industry (0.32103)	0	1	0	0	0
		B_{22}: Market concentration (0.36228)	C_{221}: The aggregation degree of Chinese LED industry in the international LED industry (0.47222)	3	6	16	13	2
			C_{222}: The market concentration of Chinese LED industry (0.52778)	0	0	0	1	0
		B_{23}: Market control (0.29365)	C_{231}: The world market share of China LED products (0.44973)	0	0	0	1	0
			C_{232}: The control of foreign-funded enterprises in China LED market (0.26212)	4	8	16	11	1
			C_{233}: The brand competitiveness of China LED product (0.28815)	2	18	14	6	0
	A_3: Policy safety (0.39085)	B_{31}: The effectiveness of domestic industrial policy (0.50797)	C_{311}: The contribution of China technological innovation encouragement policies to the increase of LED industry output value (0.40690)	5	13	14	8	0
			C_{312}: The contribution of China export promotion policies to the increase of LED industry output value (0.29055)	3	12	18	6	1
			C_{313}: The contribution of other industry support policies to the increase of LED industry output value (0.30255)	3	17	13	7	0
		B_{32}: The threat of international industry policy (0.49203)	C_{321}: The impact of international technical trade barriers on LED product export (0.35635)	0	4	14	17	5
			C_{322}: The impact of import control restrictions on LED product export (0.24841)	1	6	13	19	1
			C_{323}: The impact of intellectual property barrier on LED product export (0.39524)	1	2	16	12	9

The details of applying the new membership conversion algorithm to the fuzzy evaluation of high-tech industry safety are as follows.

(1) Calculating the target membership using the weighted sum of index memberships

Given the index memberships and weights, one classical method to determine the target membership is the weighted sum, that is,

$$\mu_k(G) = \sum_{j=1}^{m} \lambda_j(G) \cdot \mu_{jk}(G), \quad (k = 1, 2, \ldots, p) \tag{8}$$

where G denotes the evaluation target, $k = 1, 2, \ldots, p$ denotes the evaluation level, $\mu_k(G)$ denotes the target membership to the kth level, m denotes the number of evaluation indexes, $\mu_{jk}(G)$ denotes the index membership of the jth index to the kth level, $j = 1, 2, \ldots, m$, and $\lambda_j(G)$ denotes the weight of the jth index.

The index weight should guarantee the normalization constraint, that is,

$$0 \le \lambda_j(G) \le 1, \quad \sum_{j=1}^{m} \lambda_j(G) = 1 \tag{9}$$

Meanwhile, the index evaluation level should be ordered. For p evaluation levels, C_k denotes the kth level which should be superior to C_{k+1}. Given $\mu_{jk}(G)$, it should also meet the normalization constraint, that is,

$$0 \le \mu_{jk}(G) \le 1, \quad \sum_{k=1}^{p} \mu_{jk}(G) = 1 \tag{10}$$

As we can see, in order to determine the evaluation level, that is, $\mu_k(G)$, we should obtain the index membership $\mu_{jk}(G)$ and index weight $\lambda_j(G)$. In this paper, we use an AHP based method to obtain index weights and present an entropy based method to obtain index memberships.

(2) An entropy based membership conversion algorithm

The entropy concept can be used to represent the degree of disorder or randomness in the data [27]. Motivated by this, we use the entropy concept to determine the degree of concentration and dispersion in index memberships $\mu_{jk}(G)$. Let $H_j(G)$ denote the entropy of $\mu_{jk}(G)$, we use the following formulas to determine the index discrimination value for each index membership:

$$H_j(G) = -\sum_{k=1}^{p} \mu_{jk}(G) \cdot \log \mu_{jk}(G) \tag{11}$$

$$\nu_j(G) = 1 - \frac{1}{\log p} H_j(G) \tag{12}$$

$$\alpha_j(G) = \nu_j(G) \Big/ \sum_{t=1}^{m} \nu_t(G) \tag{13}$$

where $\nu_j(G)$ is an intermediate value and $\alpha_j(G)$ denotes the index discrimination value of the jth index membership. We can easily observe that $\alpha_j(G)$ also meets the normalization constraint, that is,

$$0 \le \alpha_j(G) \le 1, \quad \sum_{j=1}^{m} \alpha_j(G) = 1 \tag{14}$$

After obtaining the index discrimination value, we can calculate the effective value of the jth index to the kth level which is denoted by E_j^k, that is,

$$E_j^k = \alpha_j(G) \cdot \mu_{jk}(G), \quad (k = 1, 2, \dots, p) \tag{15}$$

Then, we can use the following steps to transfer the effective values into corresponding comparable values which can be used to calculate the target membership.

Step 1: Calculate the comparable value of the jth index to the kth level. Given the weight of the jth index to the evaluation target $\beta_j(G)$ and its corresponding effective value E_j^k, we can calculate the comparable value of the jth index to the kth level, that is,

$$F_j^k = \beta_j(G) \cdot E_j^k, \quad (k = 1, 2, \dots, p) \tag{16}$$

where F_j^k denotes the comparable value of the jth index to the kth level.

Step 2: Calculate the comparable sum of the evaluation target. After obtaining the comparable value of the jth index to the kth level, we can calculate the comparable sum of the evaluation target, that is,

$$M_k(G) = \sum_{j=1}^{m} F_j^k = \sum_{j=1}^{m} \beta_j(G) \cdot \alpha_j(G) \cdot \mu_{jk}(G), \quad (k = 1, 2, \dots, p) \tag{17}$$

where $M_k(G)$ denotes the comparable sum of the evaluation target to the kth level. Obviously, the bigger $M_k(G)$ is, the greater extent the evaluation target belongs to the kth level.

Step 3: Calculate the membership of G to C_k. By normalizing the comparable sum of the evaluation target to the kth level, we can obtain the membership of the evaluation target to the each evaluation level, that is,

$$\mu_k(G) \triangleq M_k(G) \Big/ \sum_{t=1}^{p} M_t(G), \quad (k = 1, 2, \dots, p) \tag{18}$$

Using Formulas (11)-(18), we can obtain the target membership with known index memberships and index weights. Using this algorithm, we can efficiently delete the redundant information hidden in index evaluation data without adding any priori knowledge.

5. Application and Result Discussions.

5.1. The fuzzy evaluation matrix of China's high-tech industry safety.

In order to ensure the scientific nature of the research, unlike the previous industry safety evaluation, we select both subjective evaluation indexes acquired by the experts survey and objective evaluation indexes from the patent database and department database retrieval. Meanwhile, in order to obtain fuzzy evaluation matrix, we deal with the objective indexes using the following process.

Let C_{ABC} be the Cth index in the Bth sub-criterion layer of the Ath criterion layer, $A = 1, 2, 3$, $B = 1, 2, \dots, 8$, $C = 1, 2, \dots, 26$.

In order to deal with index C_{222}, that is, the market concentration of Chinese LED industry, we use the following formula:

$$C_{222} = 1000 \times \left[\left(\frac{4501.51}{39670} \right)^2 + \left(\frac{4450.01}{39670} \right)^2 + \cdots + \left(\frac{1418.53}{39670} \right)^2 \right] = 787$$

where the data are from the website http://dazhaoming.com/html/shouyewenzhang/201606/11734.shtml which introduces the top 100 enterprises in China LED lighting industry. Then, we use the following standard: when $C_{222} \geq 1800$, it is safe; when $1400 \leq C_{222} < 1800$, it is basically safe; when $1000 \leq C_{222} < 1400$, it is normal; when

$500 \leq C_{222} < 1000$, it is unsafe; when $C_{222} < 500$, it is dangerous. Thus, we evaluate the market concentration of 2015 Chinese LED industry as "unsafe".

$\overline{C}_{ABC}$ denotes the average of C_{ABC} except C_{222} among the period from 2011 to 2015 or from 2012 to 2015. Let:

$$\Delta C_{ABC} = \frac{C_{ABC(15)} - \overline{C}_{ABC}}{\overline{C}_{ABC}}$$

where $C_{ABC(15)}$ denotes the value of index C_{ABC} in 2015.

Let $JV_{ABC} = |\Delta C_{ABC}| - CV_{ABC}$ where CV_{ABC} is the discretization factor of index C_{ABC}, and JC_{ABC} denotes the evaluation value on the safety index C_{ABC} of high-tech industry. Then, we use the following standard: when $JV_{ABC} \geq CV_{ABC}$, it is safe; when $0 < JV_{ABC} < CV_{ABC}$, it is basically safe; when $JV_{ABC} = 0$, it is normal; when $-CV_{ABC} < JV_{ABC} < 0$, it is unsafe; when $JV_{ABC} \leq -CV_{ABC}$, it is dangerous. The dealt results are as follows.

TABLE 2. The data and results of objective indexes

<table>
<tr><th></th><th>2011</th><th>2012</th><th>2013</th><th>2014</th><th>2015</th><th>CV_{ABC}</th><th>JV_{ABC}</th><th>Evaluation levels</th></tr>
<tr><td>C_{111}</td><td>21962</td><td>28729</td><td>35171</td><td>33998</td><td>34489</td><td>10.17%</td><td>0.02%</td><td>Basically safe</td></tr>
<tr><td>C_{112}</td><td>19210</td><td>23514</td><td>29129</td><td>26984</td><td>27557</td><td>9.64%</td><td>−0.63%</td><td>Unsafe</td></tr>
<tr><td rowspan="4">C_{134}</td><td colspan="5">The number of patents licensed to foreign-funded LED enterprises</td><td rowspan="4">13.52%</td><td rowspan="4">−6.61%</td><td rowspan="4">Unsafe</td></tr>
<tr><td>11416</td><td>15336</td><td>17387</td><td>16245</td><td>16423</td></tr>
<tr><td colspan="5">The number of patents licensed to Chinese LED industry</td></tr>
<tr><td>33378</td><td>44065</td><td>52558</td><td>50243</td><td>50912</td></tr>
<tr><td rowspan="4">C_{211}</td><td colspan="5">The exports of China LED products and raw materials (Ten thousand U.S. dollars)</td><td rowspan="4">35.81%</td><td rowspan="4">25.49%</td><td rowspan="4">Basically safe</td></tr>
<tr><td>N/A</td><td>1104925</td><td>1529808</td><td>2285614</td><td>4530000</td></tr>
<tr><td colspan="5">The output value of Chinese LED industry (Billion yuan)</td></tr>
<tr><td>N/A</td><td>2054</td><td>2639</td><td>3445</td><td>3967</td></tr>
<tr><td rowspan="2">C_{212}</td><td colspan="5">The imports of China LED products and raw materials (Ten thousand U.S. dollars)</td><td rowspan="2">29.55%</td><td rowspan="2">−15.47%</td><td rowspan="2">Basically safe</td></tr>
<tr><td>N/A</td><td>648016</td><td>689661</td><td>829787</td><td>912766</td></tr>
<tr><td>C_{213}</td><td>N/A</td><td>0.2607</td><td>0.3785</td><td>0.4673</td><td>0.6646</td><td>33.32%</td><td>16.78%</td><td>Basically safe</td></tr>
<tr><td rowspan="4">C_{231}</td><td colspan="5">The output value of China LED lighting industry (Billion yuan)</td><td rowspan="4">7.36%</td><td rowspan="4">−4.83%</td><td rowspan="4">Unsafe</td></tr>
<tr><td>1160</td><td>1590</td><td>2082</td><td>2757</td><td>3195</td></tr>
<tr><td colspan="5">The output value of world LED lighting industry (Billion yuan)</td></tr>
<tr><td>1272</td><td>1816</td><td>2475</td><td>3408</td><td>4363</td></tr>
</table>

In Table 2, the data of indexes C_{111}, C_{112} and C_{134} are from the patent database, and the exports and imports of China LED products and raw materials are from the China General Administration of Customs. The output value of Chinese LED industry, the output value of China LED lighting industry and the output value of world LED lighting industry are from High Industry LED Research Institute (GGII).

5.2. **The fuzzy evaluation of China's high-tech industry safety based on membership conversion algorithm.** Based on the membership conversion algorithm, we can get the fuzzy evaluation results of China's high-tech industry safety. Detailed steps are as below.

Step 1: Taking B_{11} (Technological competitiveness) as the example, the detailed steps of calculating its index membership are as follows.

a) B_{11} includes four specific indexes C_{111}-C_{114} whose evaluation matrix is:

$$U(B_{11}) = \begin{pmatrix} 0.0000 & 1.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 1.0000 & 0.0000 \\ 0.0250 & 0.3750 & 0.4500 & 0.1250 & 0.0250 \\ 0.1500 & 0.3000 & 0.2000 & 0.2000 & 0.1500 \end{pmatrix}$$

Then, based on $U(B_{11})$, we can calculate the index discrimination value and obtain the discrimination value vector:

$$\alpha(B_{11}) = \begin{pmatrix} 0.4359 & 0.4359 & 0.1186 & 0.0096 \end{pmatrix}$$

b) From Table 2, we can know the index weight vector of C_{111}-C_{114} on B_{11} is as below:

$$\beta(B_{11}) = \begin{pmatrix} 0.36431 & 0.23190 & 0.18737 & 0.21641 \end{pmatrix}$$

c) With the discrimination value vector and corresponding index weight vector, we can calculate the comparable value of the jth index to the kth level, and obtain the following comparable value matrix:

$$N(B_{11}) = \begin{pmatrix} 0.000 & 1.588 & 0.000 & 0.000 & 0.000 \\ 0.000 & 0.000 & 0.000 & 1.011 & 0.000 \\ 0.006 & 0.083 & 0.100 & 0.028 & 0.006 \\ 0.003 & 0.006 & 0.004 & 0.004 & 0.003 \end{pmatrix}$$

d) Using $N(B_{11})$, we can calculate the comparable sum of B_{11} to the kth level:

$$M(B_{11}) = \begin{pmatrix} 0.0087 & 1.6776 & 0.1042 & 1.0428 & 0.0087 \end{pmatrix}$$

e) Then, using the comparable sum $M(B_{11})$, we can calculate the membership vector of B_{11} to the evaluation level, that is,

$$\mu(B_{11}) = \begin{pmatrix} 0.0030 & 0.5903 & 0.0366 & 0.3669 & 0.0030 \end{pmatrix}$$

With the same above steps, we can obtain $\mu(B_{12})$ and $\mu(B_{13})$. Then, we can get the evaluation matrix of layout safety A_1 from its sub-criterion layer, that is,

$$U(A_1) = \begin{pmatrix} \mu(B_{11}) \\ \mu(B_{12}) \\ \mu(B_{13}) \end{pmatrix} = \begin{pmatrix} 0.0030 & 0.5903 & 0.0366 & 0.3669 & 0.0030 \\ 0.0589 & 0.2673 & 0.3902 & 0.2278 & 0.0558 \\ 0.0185 & 0.0964 & 0.1710 & 0.7018 & 0.0123 \end{pmatrix}$$

Similarly, we can get the evaluation matrices of organization safety A_2 and policy safety A_3 from their sub-criterion layers, that is,

$$U(A_2) = \begin{pmatrix} \mu(B_{21}) \\ \mu(B_{22}) \\ \mu(B_{23}) \end{pmatrix} = \begin{pmatrix} 0.0000 & 1.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0091 & 0.0182 & 0.0486 & 0.9179 & 0.0061 \\ 0.0140 & 0.0773 & 0.0772 & 0.8298 & 0.0017 \end{pmatrix}$$

$$U(A_3) = \begin{pmatrix} \mu(B_{31}) \\ \mu(B_{32}) \end{pmatrix} = \begin{pmatrix} 0.0933 & 0.3532 & 0.3694 & 0.1771 & 0.0070 \\ 0.0155 & 0.0979 & 0.3593 & 0.3981 & 0.1293 \end{pmatrix}$$

Step 2: With the evaluation matrix of layout safety A_1 from its sub-criterion layer and its corresponding weight vector:

$$\beta(A_1) = (0.32634 \quad 0.41457 \quad 0.25909)$$

we can calculate the index membership of layout safety A_1 to the evaluation target, that is,

$$\mu(A_1) = (\ 0.0182 \quad 0.3625 \quad 0.1455 \quad 0.4582 \quad 0.0155\ )$$

Similarly, we can get the index memberships of organization safety A_2 and policy safety A_3 to the evaluation target, and then obtain the evaluation matrix of 2015 China's high-tech industry safety:

$$U(G) = \begin{pmatrix} \mu(A_1) \\ \mu(A_2) \\ \mu(A_3) \end{pmatrix} = \begin{pmatrix} 0.0182 & 0.3625 & 0.1455 & 0.4582 & 0.0155 \\ 0.0063 & 0.4523 & 0.0342 & 0.5047 & 0.0025 \\ 0.0546 & 0.2261 & 0.3644 & 0.2871 & 0.0679 \end{pmatrix}$$

Then, with the weight vector of the criterion layer:

$$\beta(G) = (\ 0.29935 \quad 0.30980 \quad 0.39085\ )$$

we can calculate the target membership of 2015 China's high-tech industry safety:

$$\mu(G) = (\mu_1(G), \ldots, \mu_5(G)) = (\ 0.0149 \quad 0.4022 \quad 0.1014 \quad 0.4683 \quad 0.0132\ )$$

Step 3: Identify the evaluation result.

It is noted that the high-tech industry safety evaluation level is ordered, that is, the rank C_k is superior to the rank C_{k+1}. In this case, the maximum membership degree criterion which is applicable to the disordered situation is not applicable [28]. If the maximum membership degree criterion is used to ordered situations, some improper evaluation results could be obtained. In this paper, the five levels, that is, safe, basically safe, normal, unsafe, and dangerous, are ordered, so the higher level, i.e., safe, could be taken the lower level, i.e., basically safe. Thus, we use the following confidence criterion.

Let λ ($\lambda > 0.5$) be the confidence degree. If we calculate

$$K_0 = \min \left\{ k \left| \sum_{t=1}^{k} \mu_t(G) \geq \lambda,\ 1 \leq k \leq 5 \right. \right\}$$

then, we can judge G belonging to the K_0 level with bigger confidence degree than λ. Using this method, we judge 2015 China's high-tech industry safety as the "normal" level, since $0.0149 + 0.4022 + 0.0114 = 0.5185$. The confidence degree of the judgment is 51.85%. If we use the common maximal membership criteria, the evaluation level of 2015 China' s high-tech industry safety is "unsafe", but the membership degree is 46.83% which is lower than 51.85% by our confidence criterion.

5.3. **Result discussions.** From the evaluation results in Section 5.2, we can have the following observations.

(1) Taking the LED industry as an example, we use the membership conversion algorithm to evaluate the safety level of 2015 China's high-tech industry as "normal", with a confidence degree of 51.85%, indicating that the security status of China's high-tech industry is "normal". However, it is worth noting that the confidence degree of evaluating the safety level of 2015 China's high-tech industry as "safe" is only 1.49% which is far from the "safe" level. Thus, we should pay important attention on the safety of China's high-tech industry. From the evaluation matrix of 2015 China's high-tech industry safety, that is, $U(G)$, we know the confidence degrees of judging A_1 (layout safety), A_2 (organization safety) and A_3 (policy safety) as the "basically safe" level are 52.62%, 49.28%, and 64.51%, respectively. As we can see, the layout safety and organization safety have lower confidence degrees, which should be more strengthened by China's high-tech industry.

(2) From the evaluation matrix of industry layout safety, that is, $U(A_1)$, the confidence degree of rating B_{11} (technological competitiveness) as the "basically safe" level is 59.33%, the confidence degrees of rating B_{12} (sustainable innovation) as the "basically safe" level

and "normal" level are 32.63% and 71.64% respectively, and the confidence degree of rating B_{13} (IP control) as the "unsafe" level is 98.77%. As we can see, although China's high-tech industry technology has a certain competitiveness, the advantages mainly focus on the applications with low technical contents, and China's high-tech enterprises mainly chase short-term economic benefits with lack of sustained investment in technology development, finally resulting in a serious lack of continuous innovation. More seriously, China's high-tech enterprises are with poor patent layout capacity and low standardization, and high-tech lifelines and sophisticated technologies are monopolized by international giants. This situation may bring China's high-tech industry into the "ice century" after a brief bustling.

(3) From the evaluation matrix of organization safety, that is, $U(A_2)$, the confidence degree of rating B_{21} (extroversion level) as the "basically safe" level is 100%; B_{22} (market concentration) and B_{23} (market control) are judged as the "unsafe" level with confidence degrees being 99.38% and 99.83%, respectively. This shows that although the exports of China's high-tech products are with a rapid growth, the majority of high-tech enterprises are with small size and lack of continuous R&D investment capacity and market control. Thus, it is difficult to resist the market barriers built by international high-tech giants.

(4) From the evaluation matrix of policy safety, that is, $U(A_3)$, the confidence degree of rating B_{31} (the effectiveness of domestic industrial policy) as the "normal" level is 81.59%, and the confidence degree of rating B_{32} (the threat of international industry policy) as the "unsafe" level is 87.08%. It can be seen that the effective high-tech industry support policy is an important factor in the development of China's high-tech industry, but the international high-tech giants use their intellectual property advantages to form a market advantage and build intellectual property barriers through its agents in developed countries and various international organizations. This situation seriously hinders the development of China's high-tech industries.

6. **Conclusions.** It is of great significance to recognize the risk of international intellectual property barriers faced by China's high-tech industries and establish a pre-warning mechanism to help the government formulate industrial policies and safeguard the safety of high-tech industries. In this work, we are concerned with the safety evaluation of China's high-tech industry from the view of international intellectual property barriers. In order to deal with the issue, we consider layout safety, organization safety, and policy safety to construct an evaluation index system of China's high-tech industry safety, and then present an entropy based fuzzy evaluation algorithm. Taking the LED industry as the example, we recognize the risk level of 2015 China's LED industry and observe corresponding practical insights.

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