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Sustainable Technology Innovation Path Recognition: An Evaluation of Patent Risk of International Trade

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Abstract: Patent protection is a critical aspect of sustainable technology innovation, which is currently facing the challenge of patent risk. This study aimed to help enterprises prevent and avoid patent risk in a global view of technology innovation, and to propose a systematic evaluation model for patent risk. By combining the entropy method with the analytic hierarchy process (AHP), this study constructed an analytic hierarchy model of patent risk. Some indexes in the model were selected based on the summary of prior literature, and other indexes were selected according to experts' communication, which helped us to generalize the patent risk as comprehensively as possible. The AHP evaluation results determined the weight and relative materiality for each risk factor, which were contained in a criteria layer and a sub-criteria layer. The entropy method integrated the evaluation weights of different experts' opinions. By dividing the risk factors into three categories, namely "high", "medium", or "low", according to the priority degree, the risk priority ranking was obtained. Suggestions are discussed regarding support for enterprises in dealing with patent risk that may occur during international trade or other commercial activities.

Keywords: sustainable technology innovation; patent risk; analytic hierarchy process; entropy method; international trade

1. Introduction

With the continuous strengthening of international globalization, intellectual property (IP) rights are regarded as an indispensable condition that helps enterprises obtain core advantages in international trade competition. In particular, the progress of globalization creates an expansive worldwide market that contains massive opportunities for sustainable development. Nevertheless, risks always come with opportunities. Enterprises from developed countries are challenged by imitation or infringement while transferring products and technologies. Conversely, intellectual property infringement is also a barrier for developing countries, although infringement brings short-term benefits. By any estimation, IP infringement puzzles the equitable international trade order and has a corrosive effect on global sustainable innovation.

More and more countries are realizing the importance of intellectual property protection for international business. The implementation of the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPs) under the framework of World Trade Organization (WTO) and the Patent Cooperation Treaty promoted by the World Intellectual Property Organization (WIPO) constitutes the worldwide patent protection system. As an important component of the IP system, patents conduce scrapping trade barriers for high-tech products, thereby transforming imitation or infringement into a resolvable question pro forma. It should be noted that patent protection has territory differences between various jurisdictions. Therefore, it is difficult for the existing international patent system to ensure identical standards of patent protection for every region. This dilemma is defined as patent risk in this study, which can be regarded as the negative consequences related to the protection, transferring, and licensing of technology in international trade [1]. The major reasons for patent risk are multi-aspect and complex, with the legal system, policy environment, and market competition all with the possibility to trigger the situation. For successful, international, technology-based firms, international entrepreneurial orientation is an important factor that promotes innovation performance [2]. Thus, enterprises need to conduct well-rounded assessments of disadvantageous factors in order to prevent patent risk [3]. Evaluation purely relying on the intuition or experience of managers easily leads to bias [4]. Since the boundary of risk is abstract, obtaining specific data to illustrate the risk is very difficult. Through the fuzzy logic approach, the patent risk can be perceived on a limited scale [5]. The information uncertainties in terms of technological innovation, patent protection strength, competition situation, and other factors among trading nations are important reasons regarding the creation of patent risk, and therefore these factors should be considered in the evaluation process. The value of weight reflects the influence of the risk factor in question [6]. Tavana et al. (2010) applied the fuzzy euclid framework in their project evaluation, indicating that artificial judgement was still the core information support for the decision [7].

The main purpose of this study was to recognize the pathway of sustainable innovation through conducting a comprehensive evaluation of patent risk factors under international trade circumstances. Considering risk is a complex and chaotic system [5], patent risk is regarded as a comprehensive framework which can be perceived through multiple indicators. The assessment and precaution of patent risk play pivotal roles in international trade, in which enterprises expect to reduce the losses caused by patent infringement. On the one hand, technology-advanced enterprises need to identify the patent risk factors in advance so as to ensure that internal sustainable innovation is supported by international trade. These enterprises can take measures to achieve this, such as negotiation, litigation, and policy-making. On the other hand, since it is easy for technology-laggard enterprises to meet the patent barrier [8], they also need to discover the sources that generate risk. In fact, the patent risk is derived from the institutional difference and deficiency of patent protection from a macro-policy perspective. Therefore, institutional cooperation should be promoted for a more stable and orderly international trade system.

This paper is organized as following: Section 2 gathers and analyzes the related literature on patent risk, Section 3 specifies the research methodology, Section 4 presents the research results and analyzes the priority of patent risk factors, and Section 5 summarizes the research results and further discusses the application with suggestions.

2. Literature Review

2.1. Concept of Patent Risk

There is no clear and uniform definition for the concept of patent risk in prior research. Most of the literature discussed the risks at the institution level [4,9–12]. There are a few instances in the literature generally describing the concept of risk from the perspectives of trade balance or project management. Failure of innovation, trade losses, infringing patent rights, and infringed patent rights are all examples of consequences of patent risk in practice. Considering cross-border trade, the most obvious patent risk in international trade is that infringing products cannot be transited, especially in developed countries which have severe patent protection. For instance, Section 337 in the US is one of the remedy approaches for patent infringement, and enterprises from specific countries that have weak patent protection or goods related to specific industrial field are likely to be investigated by the International Trade Commission (ITC) of the US [13]. Conversely, in developing countries like India and Brazil, patent law is lax compared with developed countries, and inventions are harder to protect [14]. At the level of multinational corporations, patent risk presents as disputes over patent rights, such as patent license, technology transfer, enterprise merger, and acquisition, which often occur in business activities. The conflict of the patent lawsuit between Apple and Samsung in the Information Technology (IT) field is a famous case that has far-reaching influence not only on the two giant corporations, but also other companies in the IT industry [9].

As a measure for preventing unfair competition, the patent system plays an important role in international trade. Generally, a weak patent system is a trade barrier to technological innovators, whereas stronger patent protection reduces the losses that innovators may suffer, and further pushes innovation and development [15]. Nevertheless, some views propose that patent protection also results in counterproductive effects, such as patent trolls. In this situation, the patent system is used as a strategic tool without limit for damage award or social attention [16]. Qi et al. (2014) focused on the risk factors that induced overseas patent infringement litigation, and explored the relationship between patent value indicators and patent infringement litigation from a patent quality perspective [17]. In addition, the technological similarity of stakeholders, scale of development, distribution of patents, and other factors were closely related to the emergence of patent disputes [18]. These studies mainly covered specific operation processes in enterprises, and demonstrated characteristics of patent risk in different situations. Broadly, patent risk includes all adverse events related to patents, such as leaking technology secrets, patent litigation or invalidity applications, faked or infringed-upon patents, or loss of patent ownership.

The value of patents is closely associated with the potential patent risk. Lemley (2005) explored the economic concept of probabilistic patents and concluded that the value of patent rights granted by limited examination process was not stable [10]. In the process of patent evaluation, patent infringement risk should be considered first [19]. Choi et al. (2015) proposed a strategy to construct a patent pool which was used to restrict patent infringements [20]. Usually, the damage award in patent litigation is regarded as the reference when estimating the value of patent [11]. As far as patent value is concerned, greater threat of patent litigation can push the value of the patent portfolio higher [12]. Yiannaka et al. (2006) proposed a deterrence strategy to block new, innovative contenders entry to the markets [21].

Patent risk seriously hinders technology innovation, since enterprises decrease investment in research and develop (R&D) activities if patents cannot be protected effectively. Schmiele (2013) analyzed determinants to investigate the probability of IP rights infringement for multinational corporations [22]. Shin et al. (2016) analyzed the interactive relationship between the level of technology innovation and the degree of IP protection, and compared the bilateral effect presentations between the north and south of the world, from which the results indicated that the asymmetry of the IP systems would impede international trade [23]. Imitation and innovation in international trade present a situation which includes both opposition and coexistence. Doha et al. (2018) discussed the dilemma of imitators, in which imitation activities promote innovative output in quantitative terms, but cannot obtain more profit returns in a long-term development [24]. Imitation behaviors are also related to enterprises' sales volumes [25]. Buss et al. (2015) indicated that R&D outsourcing created a lot of risks related to patent infringement, and further analyzed the reduction of knowledge spillover by the allocation of property rights [26].

Based on the literature analysis above, this paper defines patent risk as a situation portfolio of possibility and consequence resulting in enterprises suffering the losses caused by patent disputes. The uncertainty in patent disputes leaves enterprises unhinged from the normal parameters with which they operate. Therefore, in this paper, the definition of patent risk involves two sides for the enterprises.

2.2. Sustainable Technology Innovation

The existing literature [27–32] promotes further understanding regarding sustainable technology innovation (STI). The concept of STI was derived from the theory of sustainable development, which involves the coordination of the relationship between economy and environment [27]. Technology development has given rise to environmental pollution in the past decades, however, technology innovation can also protect the environment by giving it greater commercial value. Pansera et al. (2016) argued that innovations coming from grassroots firms were cornerstones of sustainable development [28]. In particular, knowledge is the dominant factor in the development ceiling of enterprise, indicating that STI is an important capability when adapting to the dynamic global market [29]. Chen (2016) argued that innovation capability is among the key factors influencing STI, alongside the knowledge, production, and market dimensions [30]. Hellsmark et al. (2016) analyzed the strategic framework of a sustainable technology system, and described the policy measures for innovation system construction [31]. In the project management scenario, the sustainability was represented by a triple-bottom structure, which came from project managers' performances regarding resource utilization [32]. In these cases, STI extended the concept of people's dwelling environments toward technology innovation environments.

A perspective of view on STI is to upgrade the business model. Gallouj et al. (2015) took Europe as an example and discussed how dynamic innovation processes harmonized the contradictions of service economy development [33]. A good business model includes an optimal resource utilization plan, which guides enterprises to effectively balance between consumption and sufficiency [34]. However, business models are easily replicated by competitors, hence, only continuous innovation of a business would bring sustainable competitive advantages [35]. Baldassarre et al. (2017) analyzed the relationship between technology innovation and business models, and proposed a strategic framework for user-driven innovation [36]. The formation of a value chain promoted sustainablility in business models, and enterprises obtained more advantages if the core values were captured [37]. Schaltegger (2016) argued that the synergy mechanism among enterprise, innovation, and market promoted the evolution of business models [38]. To improve the sustainable performance of technology innovation, the sustainability assessment process for product design should also be ameliorated [39]. Niesten et al. (2017) argued that collaborations between governments and firms had important impacts on sustainability, and had the potential to overcome the challenge of environmental problems through sustainable innovation [40].

Another perspective was the construction of the STI ecological system via policy-making. Carayannis et al. (2015) argued that business models should be constitution frameworks, not strategic frameworks, which form the ecological base of technology innovation [41]. Pinkse et al. (2015) argued that the market barriers brought by incumbents enervate the sustainability of other enterprises [42]. Nevertheless, the complementary relationship between incumbents and other enterprises should not be ignored [8]. Cappa et al. (2016) emphasized that accommodative products are a better goal of technology innovation than competitive products [43]. Chang et al. (2016) identified limitations regarding China's policies of sustainable construction, revealing that policy makers should integrate innovation with the environment and society [44]. Moreover, in developing areas, the popularization and adoption of advance technology should be considered in industrial policy [45].

The evolution of STI reflects that it is grappling with challenges. Since global competition is an inevitable trend, most challenges for STI result from patent risk, which is closely related to international trade. Patent risk leads to many negative consequences of enterprises' STI strategies, such as competitive advantage recession or innovation supply deficiency. Moreover, due to the complex system feature of risk, the risk perception in the STI framework requires comprehensive evaluation considering diverse quantitative and qualitative factors. The perception method includes risk ranking, risk modeling, and risk comparison.

3. Methodology

3.1. Analytic Hierarchy Process for Patent Risk Evaluation

The analytic hierarchy process (AHP) is a quantitative and qualitative analytical method which is widely used in many fields, such as decision-making, project evaluation, and strategy planning [46]. Evaluation results indicate the priority of factors in the overall hierarchical model by the AHP method [47]. Critical factors are identified for strategic planning [48], or determinant priorities are evaluated [49]. In this analysis process, relative factors are assembled together in a hierarchic system. For risk evaluation in a specific field, a group of experts are usually required to assign weights to each factor, which are finally integrated to assess the aggregate risk. This method has proved its practicability in many cases, and it is continuously being extended into broader domains [50].

Many recent studies have tried to further improve this method to suit specific situations. Ahmadi et al. (2017) synthetically applied fuzzy failure mode and effects analysis (FFME), fuzzy-AHP, and scope expected deviation (SED) to evaluate the risk management in a highway construction project, and the developed method overcame some shortcomings seen with the generic AHP method [51]. The AHP method can also be integrated with data envelopment analysis to rank and select data [52].

According to recent research, an important research hotspot involves the improvement of the AHP method by bringing in entropy values. Using the entropy method in the process of AHP evaluation integrates the opinions of different experts and helps to reflect inconsistencies [53]. Entropy is a concept introduced from information theory to represent the degree of chaos and the corresponding amount of information in a system. Thus, through the entropy method, the weight values provided by different experts are integrated into an evaluation result, which means the opinions of these experts are balanced. Furthermore, this combination effectively reduces the subjective uncertainty produced by personal evaluation and makes the evaluation results relatively objective. The AHP method and the entropy method have good compatibility and jointly take advantage of their respective functions [54].

It should be noted that the relationship and the coordination among the factors are essential to the evaluation results of the overall systematic model. Nagpal et al. (2016) used the fuzzy-AHP method and the entropy method to evaluate utilization of website resources, and then combined the utility weights produced by these two methods to get the final evaluation score [55]. However, it should be noted that the entropy method used in most literature was developed from the factor level. A few articles [53–55] concentrated on the expert level when the entropy method was combined with the AHP method. Expert opinion usually showed multiple trends regarding the risk evaluation and were difficult to integrate. In this study, the evaluation model involving the integration of the expert opinion was more suitable for patent risk than integrating the factors alone, since combining the entropy method with the AHP model reduced the uncertainty that came from experts' ambiguous evaluations.

3.2. Research Framework

In this study, we hold the opinion that enterprises should reduce the negative influence of patent risk to realize sustainable technology innovation; thus, we considered the improved AHP method to evaluate patent risk factors. To prevent risk, enterprises need to determine the ranking of risk importance. Therefore, all possible risk factors should be fully comprehended based on strategy planning, then enterprises can make decisions according to the priorities of the risk factors. One difficulty in the evaluation of patent risk relies on the accurate description of the risk factors. There is not enough structured data to evaluate patent risk directly, and only a few cases are relevant, such as judicial judgement, administrative decision, and policy announcement. To classify the patent risk into sub-concepts, this paper extracted the main risk factors based on the literature review, and then further evaluated them based on expert opinions. On the basis of the AHP method, 7 experts were invited to provide a judging weight matrix to construct the fuzzy set of risk factors. The experts came from organizations related to patents and international trade, including administration departments, universities, and enterprises. Four experts were scholars who studied patents in Huazhong University of Science and Technology, two experts were the patent department managers of Zhongbu Zhiguang Technology Transfer Company and Light-Emitting Diode (LED) Industrial Patent Alliance, and one was the director of China's Council for the Promotion of International Trade.

Comparing the experts' judgements removed the limitation of simplicity that comes with a single judgement. This comparative judgement induced the priority sequence of risk factors [56]. Moreover, the entropy method made weight more objective [57]. Thus, with the method applied in this study, the research framework was designed as follows:

(1) Establish a hierarchy evaluation model.

The hierarchical evaluation model was based on the cases of patent risk. Through the characteristic phenomenon of patent risk in these cases, the risk factors were concluded using a method of induction. The factors were grouped together in a hierarchy evaluation model, and the hierarchy structure was divided into three levels that included the target layer (TL), the criteria layer (CL), and the sub-criteria layer (SL). The systematic structure of risk evaluation severed the purpose of considering risk comprehensively. During the modeling process, the experts also participated and provided suggestions regarding factor selection and hierarchical division.

(2) Constructing the judgement matrix.

The judgment matrix was constructed through the comparison between two risk factors that were at the same level. The value of the matrix element was the result of the comparison judgement. The evaluation basis relied on the importance of each factor, which was judged by experts who compared the importance of two factors and then gave the compared results. One comparison result was measured by an integer ranging from 1 to 9 and, correspondingly, the result was reciprocal if the two factors were compared reversely. The specific scaling solution is shown in Table 1.

Table 1. Scaling solutions and corresponding meaning.

Scale α_{ij}	Meaning
1	Compared with factor j, factor i is equally important
3	Compared with factor j, factor i is slightly more important
5	Compared with factor j, factor i is obviously more important
7	Compared with factor j, factor i is more important
9	Compared with factor j, factor i is more important
2, 4, 6, 8	Compared with factor j, the significance of factor i is between two adjacent judgement scales above
Reciprocal	If factor i is compared with factor j, the judgement value is $\alpha_{ji} = 1/\alpha_{ij}$, and $\alpha_{ii} = 1$

(3) Consistency test.

For each judgment matrix produced by experts, it was noted that all matrices needed to meet the consistency test in the AHP method. If the matrix did not meet the test, the expert provided a new judgement matrix for the CL factors or the SL factors, or even provided an evaluation result for the whole hierarchy model. In the test process, the maximum eigenvalue and the corresponding eigenvector of the judgement matrices were calculated separately. Then, the eigenvector was processed through normalization that produced the weight vector, as shown in the vector $W_i = \begin{bmatrix} \omega_{i1}, & \omega_{i2}, & \ldots, & \omega_{ij} \end{bmatrix}$. Here, the letter "$i$" represents a specific factor at the CL and the letter "j" represents a specific factor at the SL. The value in the vector represents the weight of each SL factor.

The consistency ratio (CR) is a quantitative indicator testing the consistency of judgement matrix, and its calculative formula is $\text{CR} = \text{CI}/\text{RI}$. When the value of CR was less than 0.10, the judgment matrix was considered acceptable. The calculative formula of the consistency index (CI) is $\text{CI} = (\lambda_{max} - n)/(n-1)$. The Random Index (RI) is the indicator that reflects the average consistency, which varied according to the order value of judgment matrix, as shown in Table 2.

Table 2. Average random consistency index.

Order	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

(4) Weight priority by entropy value.

The weight matrix $P_{m\times n}$ was used to present the experts' judgment results of pairwise comparison, which generated specific values for the factors in the hierarchy model. In each weight matrix, the letter "m" was the number of factors at the SL, and the letter "n" was the number of experts participating in the evaluation of the AHP. The matrix $P_{m\times n}$ was constructed as follows:

$$P_{m\times n} = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mn} \end{bmatrix}.$$

Since the judgment matrices provided by experts contained certain amounts of information, the entropy value was used to reflect upon the contribution of the experts. Further, all expert opinions were synthesized into one ranking by adjusting the entropy value. The calculation steps included three aspects. First, the entropy value of each expert's evaluation result was calculated, represented by e_i, where the calculative formula is $e_i = -k\sum_{j=1}^{m} p_{ij}Ln\left(p_{ij}\right)$, $(e_i \geq 0; i = 1,2,3,\ldots,n;\ j = 1,2,3,\ldots,m)$. The calculative formulae of arguments in the previous formula are, respectively, $k = 1/\ln(m)$ and $p_{ij} = X_{ij}/\sum_{j=1}^{m} X_{ij}$. Second, the difference coefficients g_i of the experts' opinions were calculated, where the formula is $g_i = (1-e_i)/(n-E_e)$; this way, the difference coefficient vector is calculated, which is $W_i = (g_1, g_2, g_3, \ldots, g_i)$. Third, the weight of the factors in the hierarchy model was adjusted by using the difference coefficient vector, which is $W_P = P_{m\times n}(W_i)^T$. Finally, the weight vector obtained by calculation was the comprehensive priority weight of each factor in the hierarchy model.

4. Results Analysis

4.1. Selection of Criteria Layer Factors

According to the existing literature presented hereinafter, we compiled the patent risk factors in the evaluation system, which was divided into a criteria layer and a sub-criteria layer. The factor set was submitted to many revisions through expert communication. Finally, this paper constructed a hierarchical model for patent risk evaluation, which included the following criteria layer factors and sub-criteria layer factors, as shown in Figure 1.

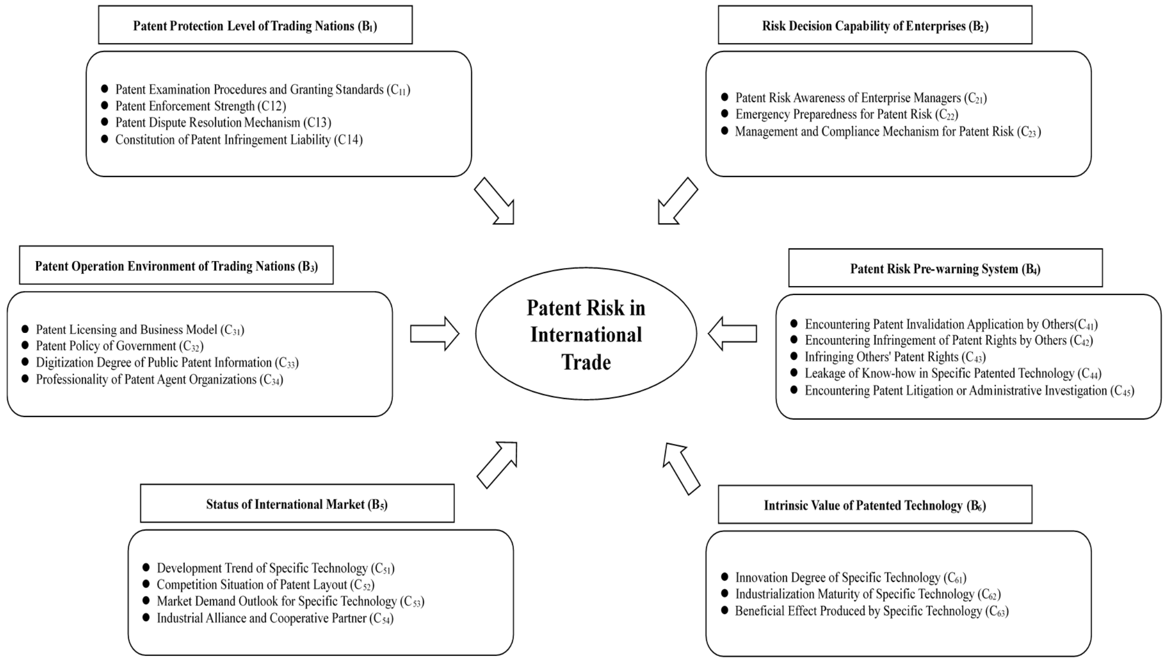

Figure 1. Evaluation system for patent risk factors.

(1) Patent protection level of trading nations.

Free-riding is usually the main concern among enterprises operating internationally. Particularly for enterprises from developed countries, technologies can be easily imitated by competitors when they enter developing markets. Conversely, when entering developed markets, enterprises from developing countries must confront challenges such as patent lawsuits or administrative investigations into patent infringement. Examination and enforcement of patents [11] are generally regarded as basic aspects of patent protection. These aspects change depending on the patent applicants [15]. Although the patent examination process confers to the applicant the privilege of technology innovation and is necessary to strengthen for more effective protection, the full life-cycle of the patent needs to be considered. Issued patents does not mean technology is substantially protected, therefore, this study added the risk factors of patent dispute resolution and constitution of patent infringement liability to the criteria layer.

(2) Risk decision capability of enterprises.

Patent risk is transmitted and expanded if left unchecked, thus a greater risk will be formed. The enterprises engaged in international trade effectively deal with patent risk using various measures. Awareness and preparedness for patent risk are necessary when enterprises engage in international trade activities [14]. However, not all enterprises determine how to make appropriate decisions when they meet patent risk. Many enterprises often face imitation [23], and lack the ability to transform imitation into innovation [24]. This challenge reflects that enterprises need management and compliance mechanisms to resolve patent risk problems. Inappropriate decisions make no contribution to control the risk, and therefore the decision capability of enterprises is also one of the most important aspects that contribute to patent risk. Thus, at the criteria layer, this study aims to investigate the patent risk factors within enterprises.

(3) Patent operation environment of trading nations.

The patent operation environment is a key component of international business for enterprises, providing the necessary conditions to allow enterprises to implement strategies and utilize their patent assets. Environmental development helps to reduce patent risk. However, patent trolls have gradually emerged with the aim of obtaining vast license fees [11]. Many countries like the US take the influence of patents on technology protection seriously, but what they adopt and the consequences are not actually the same. For example, patent policy-making [12] and patent characteristics [13] are promoted and decided according to national conditions. Patent information navigation and patent agent occupational qualities attract the attention of Chinese enterprises particularly, whose government pushes ahead related pilot projects. Therefore, to control risk, factors regarding the patent operation environment need to be considered.

(4) Patent risk pre-warning system.

The patent risk pre-warning system is another important factor that reduces the patent risk. This paper considers the factor as in the criteria layer, because China's patent administration office advocates for enterprises to construct the system. For enterprises, patent litigation, patent administrative investigation [8], and legal status changes of patents have important influence on technology management. These incidents reflect that the essence of patent infringement is core knowledge leakage, which is commonly seen in international trade [22]. Although there are many types of patent risk, enterprises can prevent the risk from expanding if they take necessary measures to prepare for potential risk factors. For example, patent litigation is usually an effective way to control risk. The main function of this is to directly prevent infringement behaviors of competitors, and insure that enterprises which bring patent lawsuits are protected from unfair competition. Therefore, this criteria layer is also an important module in patent risk management of enterprises.

(5) Status of the international market.

The status of the international market is also a main source of patent risk. Patentees and entrants are in a patent game to obtain the competitive advantage [20]. To maximize the interest of enterprises, entrants can choose between imitation and innovation [23]. The market itself also changes with technology development and the patent layout. A close relationship exists between knowledge, technology, the patent, and the market. Technology is transformed into knowledge, which is embedded in the products or services, and then knowledge flows with these specific products or services traded between markets of different nations. However, the process of knowledge flow is disrupted if there is no effective patent system that regulates knowledge obtainment and transfer. The effectiveness of the patent system depends on the market status. A market without regulation of patent infringement only leads to an overflow of counterfeit goods. At this criteria layer, the paper aims to investigate the patent risk based on the relationship between technology, the patent, the market, and entities; thus, four factors are considered at the sub-criteria layer.

(6) Intrinsic value of patented technology.

The intrinsic value of patented technology is directly related to the competitiveness of enterprises that participate in international business. The value of a patent is related to patent litigation, since damage awards is an effective way of remedying infringement [18]. The value of a technology is generally reflected by the degree of innovation, but it also requires consideration of the market and policy factors. Patent dealers pay more attention to the sales price in the market, since proven technologies are implemented according to industry standards [19] Therefore, this factor also brings patent risk for enterprises, and is necessary to be considered at the criteria layer.

4.2. Construction of Hierarchy Model to Evaluate Patent Risk

The evaluation model for patent risk was constructed by using a hierarchical structure divided into three layers. The target layer (TL) showed the objective that evaluated the patent risk in the international trade. According to this goal, 6 factors at the criteria layer (CL) were decided, as mentioned previously, and several factors at the sub-criteria layer (SL) were selected corresponding to each criteria layer. There were 23 factors at the SL altogether, as shown in Table 3.

Table 3. Patent risk assessment model.

Target Layer	Criteria Layer (CL)	Sub-Criteria Layer (SL)	Factor Meaning
Patent Risk Factors (A)	Patent Protection Level of Trading Nations (B_1)	Patent Examination Procedures and Granting Standards (C_{11})	The differences in patent systems among trading nations lead to specific technology that cannot be protected by the patent law.
		Patent Enforcement Strength (C_{12})	The strength of patent enforcement affects the effectiveness and efficiency of preventing patent infringement behaviors.
		Patent Dispute Resolution Mechanism (C_{13})	The function of the dispute resolution mechanism decides whether each party's interests in the dispute are guaranteed in a fair and reasonable way.
		Constitution of Patent Infringement Liability (C_{14})	The clarity and compensation of patent infringement liability decide whether patent infringement and free-riding can be prevented effectively.
	Risk Decision Capability of Enterprises (B_2)	Patent Risk Awareness of Enterprise Managers (C_{21})	The speed and accuracy of patent risk awareness result in whether enterprises avoid loss beforehand.
		Emergency Preparedness for Patent Risk (C_{22})	The immediate solution for emergent patent risk decides whether risk results are controlled to a bare minimum.
		Management and Compliance Mechanism for Patent Risk (C_{23})	The execution degree of these mechanism affects the effectiveness and efficiency of resolving the patent risk problem.
	Patent Operation Environment of Trading Nations (B_3)	Patent Licensing and Business Model (C_{31})	The license type and revenue amount affects the sustainability of international businesses relative to the specific technology.
		Patent Policy of Government (C_{32})	The specific regulation of policy decides whether some kinds of international business activities are recognized legally (e.g., technology transferring).
		Digitization Degree of Public Patent Information (C_{33})	The construction progressing of patent information infrastructure affects the awareness for potential patent risk and uncertainty.
		Professionality of Patent Agent Organizations (C_{34})	The serviceability of the patent intermediary agencies affects the quality of patent protection and commercialization of specific technology.
	Patent Risk Pre-Warning System (B_4)	Encountering Patent Invalidation Application by Others (C_{41})	The invalidation probability for specific patents affects the competitive advantage of enterprises in international business.
		Encountering Infringement of Patent Rights by Others (C_{42})	The probability of this situation affects the fair competition of enterprises in international business.
		Infringing Others' Patent Rights (C_{43})	The probability of this situation affects the capacity of enterprises to enter the international trading market.
		Leakage of Know-How in Specific Patented Technology (C_{44})	The probability of this situation affects the competitive advantage of enterprises in international business.
		Encountering Patent Litigation or Administrative Investigation (C_{45})	The result of these emergency events decides whether enterprises enter the international trading market.

Table 3. *Cont.*

Target Layer	Criteria Layer (CL)	Sub-Criteria Layer (SL)	Factor Meaning
	Status of the International Market (B_5)	Development Trend of Specific Technology (C_{51})	Whether enterprises' technologies keep up with trends or not changes the value chain of enterprises.
		Competition Situation of Patent Layout (C_{52})	Enterprises' strategies of patent layouts are affected by the competitive situation, which has uncertainty in R&D activities.
		Market Demand Outlook for Specific Technology (C_{53})	The market demand for specific technology affects the R&D activities of enterprises and further decides enterprise development strategies.
		Industrial Alliance and Cooperative Partner (C_{54})	The collaboration among enterprises leads to risk sharing which lowers the real risk of each enterprise.
	Intrinsic Value of Patented Technology (B_6)	Innovation Degree of Specific Technology (C_{61})	The degree of innovation decides the competitive capacity and also leads to technological imitation and free-riding behaviors.
		Industrialization Maturity of Specific Technology (C_{62})	The degree of industrialization reduces the cost of R&D activities and affects the probability of success in trading nations.
		Beneficial Effect Produced by Specific Technology (C_{63})	The beneficial effects of technology, such as cost reduction, performance improvement, and pollution reduction, decide whether trading nations accept technology.

Based on the evaluation model constructed, 7 experts in the field of patent related were invited to evaluate the importance priority of all of the factors in the hierarchy evaluation model. The evaluation process was performed using pairwise comparison and scaling scores for each judgment matrix were provided. The patent risk was recognized in different aspects using this method. Although opinions of these experts differed, they were mutually complementary, which helped to reduce the prejudice of the patent risk.

4.3. Evaluation Results and Risk Priority Ranking

(1) Judgment matrices and consistency testing.

All expert opinions were collected into the judgment matrices based on scaling values. The characteristic roots of these judgment matrix were calculated respectively. Then, the scaling values were normalized and converted to the weight values of the factors. Furthermore, the consistency of each expert was tested and the CR values were all less than 0.1, as shown in Table 4. Therefore, these judgment matrices were considered acceptable.

Table 4. Consistency test results.

CR	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7
A	0	0.0464	0.0397	0.073	0.0664	0.0548	0.0041
B_1	0.0226	0.0562	0.0551	0.0858	0.0551	0.0438	0.0005
B_2	0	0.037	0	0.0311	0.037	0.037	0.0036
B_3	0	0.0162	0.0302	0.0349	0.0582	0.0438	0.0023
B_4	0	0.0202	0.0231	0.0636	0.0122	0.0375	0.0043
B_5	0	0.0562	0.0252	0.0545	0.0677	0.0962	0.0093
B_6	0	0.037	0.0516	0.0825	0.0825	0.0772	0.0036

(2) Entropy method synthesis.

Based on the judgment matrices, the entropy value of each expert opinion was calculated and the weight values obtained by the AHP method were further adjusted. The weight values of the AHP evaluation and the values adjusted by entropy are shown in Table 5. The weight values among the experts noticeably differed, and the adjusted values played an important role in balancing the gap between the experts' opinions by synthesizing these weight values into a new one. The balance effect was more obvious in the factors at the SL than the factors at the CL. Compared to the average of the experts' weight values, the adjusted values presented the nonlinear characteristic in the decision process, which was promoted by multiple experts. According to the results, the most important factor at the CL was "Patent Operation Environment of Trading Nations" (B_3), and the most important factor at the SL was "Emergency Preparedness for Patent Risk" (C_{22}).

Table 5. Priority weight of each factor.

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Mean	Adjusted
B_1	0.2353	0.1166	0.0604	0.2604	0.2908	0.1424	0.0608	0.1667	0.1697
B_2	0.4706	0.1166	0.0362	0.0694	0.3979	0.0953	0.3443	0.2186	0.2133
B_3	0.1176	0.4172	0.3222	0.1515	0.1454	0.4016	0.1696	0.2464	0.2428
B_4	0.0588	0.2641	0.0263	0.4525	0.0589	0.0524	0.3255	0.1769	0.1804
B_5	0.0588	0.0551	0.1931	0.0400	0.0716	0.2768	0.0643	0.1085	0.1071
B_6	0.0588	0.0305	0.3617	0.0262	0.0355	0.0316	0.0356	0.0828	0.0866
C_{11}	0.1061	0.0068	0.0371	0.1469	0.1626	0.0375	0.0401	0.0767	0.0786
C_{12}	0.0530	0.0313	0.0064	0.0314	0.0353	0.0078	0.0082	0.0248	0.0242
C_{13}	0.0446	0.0645	0.0139	0.0401	0.0747	0.0168	0.0082	0.0375	0.0369
C_{14}	0.0315	0.0140	0.0030	0.0420	0.0181	0.0803	0.0042	0.0276	0.0276
C_{21}	0.2690	0.0122	0.0052	0.0489	0.0417	0.0100	0.0377	0.0607	0.0588
C_{22}	0.0672	0.0301	0.0103	0.0058	0.2535	0.0246	0.2002	0.0845	0.0829
C_{23}	0.1345	0.0743	0.0207	0.0146	0.1028	0.0607	0.1064	0.0734	0.0708
C_{31}	0.0294	0.1631	0.2132	0.0137	0.0085	0.0221	0.0877	0.0768	0.0784
C_{32}	0.0294	0.0630	0.0184	0.0343	0.0175	0.1058	0.0196	0.0411	0.0402
C_{33}	0.0294	0.1631	0.0320	0.0082	0.0804	0.0473	0.0207	0.0544	0.0518
C_{34}	0.0294	0.0282	0.0586	0.0953	0.0390	0.2264	0.0415	0.0741	0.0759
C_{41}	0.0131	0.0215	0.0138	0.0143	0.0090	0.0254	0.1590	0.0366	0.0335
C_{42}	0.0065	0.0529	0.0042	0.1211	0.0049	0.0023	0.0578	0.0357	0.0333
C_{43}	0.0065	0.0529	0.0014	0.2240	0.0254	0.0045	0.0578	0.0532	0.0510
C_{44}	0.0065	0.1228	0.0042	0.0622	0.0032	0.0127	0.0191	0.0330	0.0295
C_{45}	0.0261	0.0140	0.0027	0.0309	0.0164	0.0076	0.0318	0.0185	0.0177
C_{51}	0.0294	0.0066	0.1068	0.0020	0.0096	0.0289	0.0057	0.0270	0.0306
C_{52}	0.0098	0.0148	0.0110	0.0108	0.0192	0.0623	0.0149	0.0204	0.0205
C_{53}	0.0098	0.0032	0.0477	0.0040	0.0049	0.0135	0.0315	0.0164	0.0175
C_{54}	0.0098	0.0305	0.0276	0.0232	0.0378	0.1721	0.0122	0.0447	0.0458
C_{61}	0.0336	0.0194	0.0979	0.0164	0.0033	0.0045	0.0039	0.0256	0.0284
C_{62}	0.0168	0.0079	0.0308	0.0073	0.0099	0.0240	0.0110	0.0154	0.0162
C_{63}	0.0084	0.0032	0.2330	0.0025	0.0222	0.0030	0.0207	0.0419	0.0500

(3) Risk priority ranking.

The weight priority of all of the patent risk factors provided guidance for enterprises to implement their patent strategy. By ranking the weight value, this study divided all factors of patent risk into three levels, namely, high, medium, and low. The higher the risk level was, the more concern was indicated for the enterprises. Each risk level had a weight range, which is shown in Table 6. These three levels corresponded respectively to a specific priority at the CL and the SL.

Table 6. Priority criteria for patent risk indicators.

Level	Priority (CL)	Weight Range	Priority (SL)	Weight Range
High	I	(0.2, 1)	I	(0.06, 0.1)
Medium	II	(0.14, 0.2)	II	(0.02, 0.06)
Low	III	(0, 0.14)	III	(0, 0.02)

The priority ranking results are shown in Table 7, from which the priority of the factors at the CL and the SL can be seen separately. For the factors at the CL, the results revealed that "Risk Decision Capability of Enterprises" (B_2) and "Patent Operation Environment of Trading Nations" (B_3) were the high-risk factors, indicating that enterprises have more direct and stronger ties with these two factors than the other four factors. In comparison, the medium risk factors bring troubles usually from a more macro perspective. This illustrated that the ultimate form of patent risk depends on the international business strategy; furthermore, the familiarity with the international business paradigm is the key element to the successful strategy of enterprises. Therefore, enterprises must firstly enhance the capability of these two aspects. It was expected that "Status of International Market" (B_5) and "Intrinsic Value of Patented Technology" (B_6) were the low risk factors, since these two factors have long-term influences indirectly upon enterprises rather than causing immediate risk.

Table 7. Priority ranking of each factor.

TL	CL	Weight	Priority	SL	Weight	Priority
A	(B_1)	0.1697	II	(C_{11})	0.0786	I
				(C_{12})	0.0242	II
				(C_{13})	0.0369	II
				(C_{14})	0.0276	II
	(B_2)	0.2133	I	(C_{21})	0.0588	II
				(C_{22})	0.0829	I
				(C_{23})	0.0708	I
	(B_3)	0.2428	I	(C_{31})	0.0784	I
				(C_{32})	0.0402	II
				(C_{33})	0.0518	II
				(C_{34})	0.0759	I
	(B_4)	0.1804	II	(C_{41})	0.0335	II
				(C_{42})	0.0333	II
				(C_{43})	0.0510	II
				(C_{44})	0.0295	II
				(C_{45})	0.0177	III
	(B_5)	0.1071	III	(C_{51})	0.0306	II
				(C_{52})	0.0205	II
				(C_{53})	0.0175	III
				(C_{54})	0.0458	II
	(B_6)	0.0866	III	(C_{61})	0.0284	II
				(C_{62})	0.0162	III
				(C_{63})	0.0500	II

For the factors at the SL, the results revealed that "Patent Examination Procedures and Granting Standards" (C_{11}), "Emergency Preparedness for Patent Risk" (C_{22}), "Management and Compliance Mechanism for Patent Risk" (C_{23}), "Patent Licensing and Business Model" (C_{31}), and "Professionality of Patent Agent Organizations" (C_{34}) were the high-risk factors. In addition, there were 15 factors ranking in priority II and 3 factors ranking in priority III. The results revealed that the protection and utilization of patent assets were the core strategies in controlling patent risk. The knowledge intensive and skill intensive in products or service is an inexorable trend that appears more obviously.

5. Conclusions

Patent risk prevention is one of the important ways to enhance enterprises' core competitiveness in the global value chain, but it is also an unavoidable problem, especially for enterprises that plan to enter the international market for the first time. Based on the AHP method and the entropy method, this paper evaluates the essential patent risk factors which are compared from the perspective of sustainable technology innovation. A competitive advantage is helpful to reduce the risk of product development strategy [58], therefore, enhancing IP management capability is an effective way to prevent patent risk [59]. Furthermore, the weight values used in our analysis indicate the priority sequence of patent risk factors, which guide decision-makers in enterprises to generate corresponding strategies. From these analysis results, suggestions for enterprises involved with international trade can also be concluded.

First, the process of upgrading the industry and technology should be promoted persistently. One of the key elements of success in sustainable technology innovation lies in open strategies [60]. Enterprises who have a head-start on technologies obtain greater discourse power and play a more important role in the value chain of an industry. This strategy is preliminary and necessary to withstand various kinds of patent risk.

Second, the consciousness of patent risk prevention should be raised. The ability to identify patent risk has a direct impact on sustainable implementation of enterprise patent strategy. For the transformation toward STI, dynamic technology convergence creates more chances of obtaining benefits [61]. Enterprises need to be familiar with patent systems and rules at home and abroad in order to quickly grasp patents and first-hand dynamic market competition information. Enhancement of this ability prevents the risk evolving into a worse situation.

Third, the construction mechanism of patent risk management should be strengthened. Management mechanism is a systematic project which involves various aspects. In the process of dealing with patent risk, organizing, coordinating, and communicating with people efficiently helps enterprises respond to emergencies more rapidly. In addition, international market and technology trends change rapidly, and it is difficult to compete in international trade solely by the strength of one enterprise. Thus, effective cooperative mechanisms are also important.

There are some limitations in this study which we will explore further in future research. Generally, this paper analyzed the external characteristics without focusing on the inner mechanism of patent risk formation. For example, the cause of patent risk is not presented in this study. This evaluation of patent risk provides an overview which could help enterprises construct the capability of risk perception and recognize the path that resolves the risk. However, this study cannot explain why and when patent risk happens. Furthermore, the research method applied in this study only provides an exploratory understanding of the patent risk. To reveal the interaction among the patent risk factors, the research method needs to be improved by combining some other methods, such as interview and survey.

Therefore, in future studies, we plan to further explore the determinants of some specific patent risks, such as patent imitation risk, patent infringement risk, and patent litigation risk. By concentrating on these specific aspects, future research could aim to explore the relationships between risk formation and enterprise patent strategy. Empirical methods should be applied to further improve this research, combined with AHP and entropy methods. For patent risk formation, patent litigation data should be collected to describe the formation process of patent risk. Regarding enterprises' patent strategy, we plan to collect the patent data of litigants to observe enterprises' strategic directions regarding patent layouts. In the scenario of patent risk, we expect to apply the pattern of risk formation to international trade policy, thereby supporting sustainable technology innovation through more effective patent protection.

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