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Dynamic Credibility Evaluation on High-tech Enterprise Partners in Knowledge Collaboration Using a SPA-Markov Model

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ABSTRACT

An evaluation on high-tech enterprise research and development (R&D) is of great necessity for boosting innovative economy and high-tech industry in the era of knowledge economy. However, high-tech enterprises cannot fully understand their partners' R&D capabilities and cooperative tendencies due to information asymmetry. Driven by interest, opportunistic behaviors might emerge, reducing trust and affecting efficient R&D cooperation. To explore R&D partners' credibility and avoid opportunistic behaviors, this study establishes an evaluation index system on the credibility of high-tech enterprise partners based on literature extraction and law relationship. The SPA-Markov Model has been adopted to dynamically evaluate the credibility in knowledge collaboration. Finally, HS, the China FAW Tooling Die Manufacturing's partner, is case-studied to verify feasibility of the model. The results are as follows: (1) Social environment, partner competence, partnership and collaborative potential are key indexes measuring partner credibility. (2) The SPA-Model Model could figure out changes and trends of the credibility. (3) The credibility of high-tech enterprise partners might fluctuate in collaboration. According to the study, the SPA-Model Model is feasible for assessing the credibility, which makes up for static evaluation and provides novel ideas on evaluation and optimization of high-tech enterprise partners.

Keywords: high-tech enterprises, knowledge collaboration, credibility, dynamic evaluation

INTRODUCTION

In the era of knowledge economy, knowledge collaboration has been vital for efficient knowledge creation in various fields, especially in the knowledge-intensive high-tech industry (Kraaijenbrink et al., 2007). Based on mutual benefits, different participants establish strategic cooperation to strive for knowledge, technology and resource synergy as well as jointly solve technical problems in industrial development. However, different social divisions of labor and knowledge properties result in high information asymmetry; accordingly, high-tech enterprises fail to fully understand partners' scientific and research capabilities, real investment as well as cooperative tendency. Driven by interest, opportunistic behaviors might possibly appear, damaging common interest as well as hindering effective collaboration and creation. Among over 800 US enterprises surveyed since 1990s, only 40% have maintained strategic cooperation of over four years; while others interrupted collaborations in the short run, dragging down creative participants' enthusiasm of cooperative research and development (R&D) seriously. As R&D innovation in high-tech industry is featured with long cycle, high risk and strong uncertainty, fluctuations of strategic collaborations would curb efficiency of R&D innovation greatly and even end the innovation. In practice, strategic cooperation between partners mostly depends on mutual trust, which is a kind of dependency or psychological contract. It has been important for uncertain and dependent social interaction. In the process of R&D innovation, trust can affect efficiencies of knowledge transfer, sharing and collaboration among participants (Walrod, 1999; Chen et al., 2010; Roumani et al., 2017).

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Contribution of this paper to the literature

- The SPV-Markov Model has been employed for dynamic evaluating credibility of high-tech enterprise partners, the evaluation index system has been settled through literature extraction and law relationship, lacking expert consultations or practical investigations including trust mechanism explorations through discourse analysis, grounded theory and scenario analysis.
- A combination of SPA and Markov Chain has capacitated dynamic, continuous assessment on partner credibility, as well as objectively reflected credibility conditions in different periods. It benefits judging trustworthiness of partners in cooperation and discovering opportunistic behavior timely so that effective measures could be taken to reduce risks. The model, easy in calculation and operation as well as reliable in results, could make real and overall measurement of dynamic situation and future trend.

Objective and efficient evaluations on high-tech enterprises' credibility would deepen mutual understanding and cognition as well as reduce probability of opportunistic behaviors. Accordingly, it helps to gather advantageous resources or knowledge, trigger knowledge collaboration, push higher cooperative interest among creative participants, as well as boost efficient innovations among high-tech enterprises (Belkadi and Bernard, 2015). However, limitations of previous research methods result in failure of objective evaluations on participant credibility. For instance, the multi-level fuzzy comprehensive evaluation could overcome the drawback of sole solution in traditional mathematic methods and get multi-layer solutions according to different possibilities; however, it cannot reflect the randomness of trust objectively and avoid information duplication caused by evaluation index correlations (Hu, 2012). The analytic hierarchy process can be applied to conditions with uncertain appraised targets and subjective information. The subjective judgment is obvious through being expressed and processed in quantitative form. However, the result quality is dragged down as the result is not any exact real number. The gray clustering evaluation sets no specific requirement on sample size and does not demand a typical distribution; nonetheless, there lies no measure on whether the specified weight is fair or effective (Tan and Zhao, 2009). Therefore, objective and comprehensive evaluations on credibility trend of high-tech enterprise partners would be of great help for keeping abreast of partners' behavioral tendency, adjusting cooperative strategies scientifically, as well as lowering collaboration risks.

LITERATURE REVIEW

It has been widely acknowledged that partnership combines two or more enterprises with supplementary core competitiveness as well as enable them to enter new market, overcome trade barriers or introduce of new products, despite requirement of equal risks and contributions in cooperation (Mason, 1993). Brouthers et al. (1995) developed "4CS" analysis framework to help enterprises avoid selecting wrong partners, stating that complementary skill, cooperative cultures, compatible goals and commensurate level so frisk would be necessary in cooperation. Meanwhile, as partner evaluation is a process of multi-criteria, finite-alternative decision making with several uncertain factors, a scientific and effective judgment method would guarantee objective results (Meng and Deng, 2003). Currently, comprehensive evaluation methods including analytic hierarchy process, fuzzy comprehensive evaluation method, neural network method, genetic algorithm, particle swarm optimization, etc (Tam and Tummala, 2001; Mikhailov, 2002; Wang et al., 2009; Zhao et al., 2008; Chen et al., 2010). Specifically, Guo (2003) and Liu et al. (2004) adopted methods of analytic hierarchy process and fuzzy comprehensive evaluation respectively to make judgment on virtual enterprise partners. As the two methods have been mainly dependent on subjective judgment of experts and scholars, the results would not be absolutely objective as uncertainty and ambiguity of matters might affect experts' evaluation (Wang and Lu, 2017). You et al. (2014) established a Gray-Fuzzy evaluation model to combine weighting based on analytic hierarchy process and entropy value, which aimed to comprehensively evaluate candidate partners with breakthrough technological innovation. Through combing expert experience and objective information, the method has done well in gray comprehensive analysis of ambiguity and human brain judgment during the process of evaluation and sorting (Hsueh et al., 2016); however, it has not taken time into consideration and ignored development of partners. Feng et al. (2000) employed genetic algorithm to select virtual partners. Although it has succeeded in seeking out partners satisfying constraint conditions from tremendous candidates, the method witnesses slow search velocity when approaching to optimum and is even easily trapped into the local optimal solution. Accordingly, it is difficult to adopt in practice. Above all, most scholars have adopted traditional static evaluation methods to make comprehensive judgment on partners. Nonetheless, the methods are not suitable for high-tech enterprise partners considering multi-stage, high uncertainty and information asymmetry in the course of high-tech innovation. That is, static evaluation fails to cover the whole process of reaching equilibrium and measure partners' performance in future collaborations.

As for credibility, most discussions have concentrated on the effect of partner trust. Kaser and Miles (2001) discovered positive correlations between credibility and knowledge sharing incentive through case study. Halil et al. (2016), through a combination of qualitative and quantitative analysis, figured out that frequency and effectiveness of communication would act as influential factors on trust. Based on ISAs studies, Sklavounos et al. (2015) stated that perceived risk of opportunism would have negative impact on partner credibility. Elmuti et al. (2005) pointed out through revealing essence of strategic alliance that credibility has had great influence on partnership. Lower credibility would weigh on partnership, bring risks to the alliance, and endanger stability of collaborations among R&D participants. Based on the R&D cooperation project concluded by 376 German chemistry and biology professors, Niedergassel and Leker (2011) demonstrated that higher credibility among alliance members would benefit R&D innovations and partnership. Bunduchi (2013) clarified through case study that credibility among partners might affect new partner selection and cooperative innovation performance, and that an increasing credibility would help with partnership management. Above all, previous studies, having taken credibility as a key influential factor on partnership, have little quantified trust based on systemic evaluation framework. Besides, the studies have not fully considered the dynamic feature of credibility in cooperation, resulting in a lack of model from dynamic perspective. Accordingly, an evaluation index system is built to measure high-tech enterprise partners in knowledge collaboration in this paper. The Set Pair Analysis (SPA) is selected to reflect connection degree of partners and explore credibility tendencies based on identity-discrepancy-contrary (IDC) inference. Meanwhile, Markov Chain is introduced to establish SPA-Markov Model for dynamic assessment. Finally, feasibility and reliability of SPA-Markov dynamic evaluation model have been checked through empirically measuring credibility of HS, the partner of FAW Tooling Die Manufacturing Co., Ltd.

The layout of this paper is as follows. Evaluation index system on credibility of high-tech enterprise partners in knowledge collaboration is established in Section 3 based on literature extraction and law relationship. Credibility of high-tech enterprise partners is calculated on the basis of SPA. Besides, we combine Markov Chain Model, in which intermonth transition matrix is used to predict connection degree of next period based on the degree of previous month. Accordingly, the credibility could be judged dynamically. In Section 4, HS, the partner of FAW Tooling Die Manufacturing Co., Ltd, has been adopted for case study. Through observing its credibility within one year, we prove feasibility of SPA and Markov Chain in dynamically evaluating credibility of high-tech enterprise partners. Section 5 summaries study results.

METHODOLOGY

Evaluation Index System on Credibility of High-tech Enterprise Partners in Knowledge Collaboration

Literature extraction-based evaluation index

There have been many factors influencing trust among partners in cooperation. For instance, according to survey on over 1,000 suppliers in automobile industry, Sako and Helper (1998) contributed influential factors to reputation, written agreement, long-term trade, promise, dependency, asset exclusion, technical assistance, interaction, uncertainty, etc. Having considered trust multi-dimensional in strategic alliance, Das et al. (2001) concluded that control level, communication, organization matchup and cultural fusion would affect credibility. Nielsen (2004) diversified roles of trust playing during different phases as well as explored influential factors covering previous cooperation experience, reputation, information transparency and security mechanism. Throughout relevant literature on credibility, factors mentioned frequently include ability, reputation, promise, communication, cooperation experience and information sharing. Due to space limitation, influential factors on trust in domestic and international researches could not be listed comprehensively in this paper. This study takes trust, reliance and credibility as key words for bibliographic retrievals on Web of Science, Google Scholar, as well as Chinese National Knowledge Infrastructure (CNKI). Accordingly, 44 papers about credibility among enterprises, cooperation alliances or supply chains have been selected. Based on the selections, influential factors, researchers and years of publication have been sorted out. Through literature extraction, a network diagram (**Figure 1**) on these factors has been worked out with adoption of Ucinet. In the diagram, trust is taken as the center; blue squares outside indicate domestic and overseas scholars proposing the factors; and red dots insides imply influential factors. Relatively large dots refer to the factors widely recognized among most scholars.

According to **Figure 1**, significant factors mostly discussed in domestic and overseas literature include ability, promise, reputation, communication, cooperation experience, dependency and culture. Ability has appeared as one of the most frequent presences. Trust on competence enables trustors to meet demands of trustees more easily and collaborate with trustees more actively (Hewett and Bearden, 2001). Promise would improve relations among enterprises as well as promote establishment of a trustful and cooperative partnership (Sako and Helper, 1998). Reputation holds great significance in building initial trust, since it serves as a major reference among enterprises with no previous trading record. Communication could decrease conflicts and uncertainty in cooperation so as to

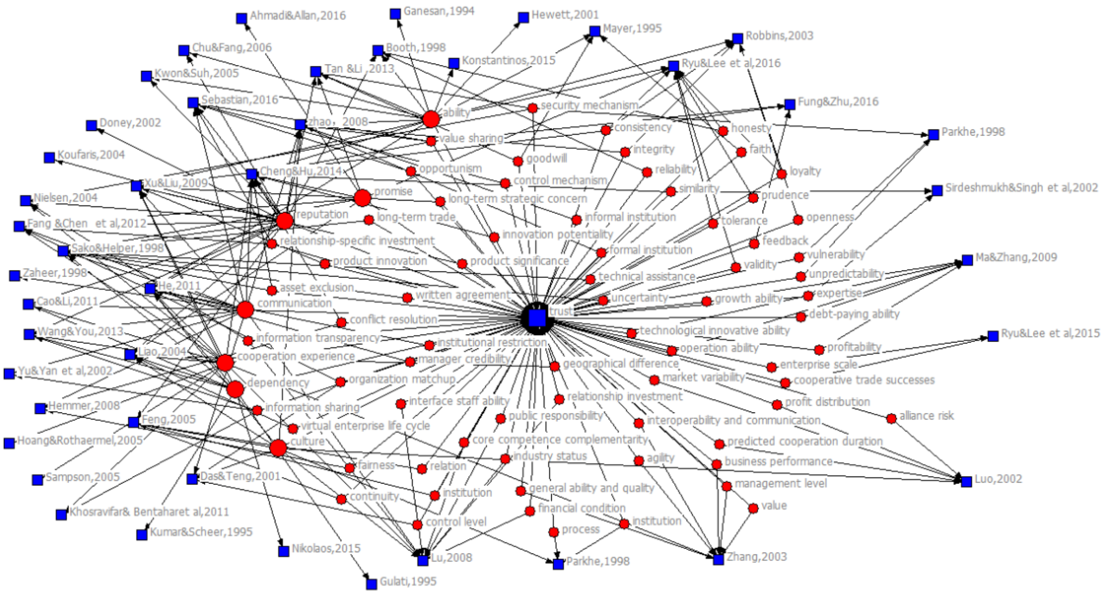

Figure 1. Network diagram on trust influential factors via literature extraction

enhance credibility (Bunduchi, 2013). Enterprises with rich cooperation experiences would better deal with uncertainty in cooperation, which helps to maintain trust among partners (Anand and Khanna, 2000). Higher mutual dependency indicates better resource and ability integrations, correspondingly higher cooperation effectiveness (Gulati, 1995). Cultural difference might spur misunderstanding, conflicts and disputes among partners, which further results in imbalanced collaboration (Liao, 2004).

Law relationship-based credibility evaluation index selection

Law relationship refers to an interlocking system of theoretical or rational relations among important concepts including original model, antecedent variable and outcome variable. Having been extensively applied in the fields covering psychology, management, economics and education, it could reveal causality among multi-variables scientifically. In evaluating credibility of high-tech enterprise partners in knowledge collaboration, it shall firstly settle what aspects to reflect trust among partners and what antecedent variables to affect their credibility. Assuming that knowledge collaboration is one of the outcome variables on credibility of high-tech enterprise partners, the law relationship shall be a collection of correlations among antecedent variables (influential factors on trust), trust and outcome variables (including knowledge collaboration) as well as interior structures of each conception. Based on law relationship, this paper studies influential factors in aspects of social environment, partner competence, partnership and cooperative potential so as to verify reasonability of primarily elected indexes for assessing partner credibility.

(1) Social environment and knowledge collaboration

In the dynamic market, technological innovation requires advantageous knowledge and resources among a pool of enterprises and organizations, rather than sole enterprise or organization, to cope with market uncertainty. Government support would protect smooth progression of knowledge collaboration among high-tech enterprise partners. Specifically, government would provide financial subsidies and preferential tax policies for R&D cooperation (Liao, 2004). Greater support and guidance of government policies might result in more stable cooperation and deeper trust, which further spur knowledge collaboration in partnership. Conflicts and interest disputes seem inevitable considering cultural and value differences as well as information asymmetry; while a systemic legal system could provide solution for this obstacle, lead to sound credibility and support knowledge collaboration among partners. Above all, market uncertainty, government support and legal guarantee are significant in credibility maintenance and knowledge collaboration amid high-tech enterprise partnership in the aspect of social environment.

(2) Partner competence and knowledge collaboration

Trust in partner competence could facilitate knowledge exchange and transfer; while recognition of competence adds trust for partner capability in knowledge learning, comprehension and absorption (Merchant, 1997). It would thereby stimulate synergies like knowledge acquisition, transfer and creation in R&D cooperation. In the meanwhile, organic knowledge collaborations, as cross-organizational cooperation among high-tech enterprises,

Table 1. Evaluation index system on credibility of high-tech enterprise partners in knowledge collaboration

Primary Index	Secondary Index	Primary Index	Secondary Index
Social environment collaboration	Market uncertainty	Partner competence collaboration	R&D competence
	Government support		Entrepreneurial ability
	Legal guarantee		Reputation
Partnership collaboration	Communication		Cooperation experience
	Promise	Cooperative potential collaboration	R&D and innovation potentials
	Dependency		Culture compatibility
	Sharing		Cooperative willingness
	Conflict resolution mechanism		Organizational matchup

would not live without coordination among managers. Reputation of partners could not be neglected as well considering its huge effect on establishing trust initially (Cheng et al., 2014). When cooperating with someone without any touch previously, reputation serves as a key factor for measuring credibility. That is to say, partners with high reputation would earn trust easily, which sparks willingness of knowledge exchange and transfer as well as boosts knowledge collaboration. In addition, compared with partners in a first business contact, enterprises tend to trust those they have worked with before (Koufaris and Hampton-Sosa, 2004). It saves time and cost for mutual adaptation and matching, which benefits knowledge collaboration. As a result, R&D competence, entrepreneurial ability, reputation and cooperation experience would promote credibility maintenance and knowledge collaboration in the high-tech enterprise R&D cooperation.

(3) Partnership and knowledge collaboration

Communication could reduce conflicts in cooperation, trim uncertainty and strengthen mutual trust (Niedergassel and Leker, 2011); therefore, it is necessary for realizing knowledge collaboration. Promise, representing an intention for long-term cooperation, is irreplaceable for maintaining a stable partnership (Liao, 2004). It guarantees persistent credibility and supports steady knowledge collaboration. Mutual dependency among partners is considered as the premise of cooperation. Stronger dependency would result in larger possibilities of active cooperation when participants are caught in different nodes along the knowledge chain for some technological innovation; besides, it lowers probability of conflicts and therefore prompts knowledge collaboration. Partners shall not only focus on mutual dependency but value resource sharing as well. High-tech enterprise R&D cooperation requires communications and advantageous resource sharing so as to uplift mutual knowledge storage, generate knowledge collaboration, promote knowledge creation and accelerate R&D efficiency. Conflicts among participants are unavoidable in cooperative R&D activities. Moderate conflict benefits synergetic development as it impels mutual criticism and self-criticism amid participants; while extravagant conflict would destroy mutual trust, weaken willingness of knowledge transfer and impede knowledge collaboration. Accordingly, communication, promise, dependency, sharing and conflict resolution mechanism are beneficial to credibility maintenance and knowledge collaboration in R&D cooperation.

(4) Cooperative potential and knowledge collaboration

R&D and innovation potentials serve as a key factor in assessing whether a partner is worthy of long-term trust. Development potentials, as impetus for continuous progress, settle future competitive powers of partners (Mohr and Spekman, 1994). Culture compatibility is significant for high-tech enterprises selecting partners (Xue and Zhang, 2010) as well as for knowledge collaboration among high-tech enterprises. Cultural difference would hinder information exchange and knowledge transfer, which goes against knowledge collaboration. Cooperative willingness is considered as participants' subjective psychological tendencies toward combined efforts, covering their cognition, attitude and motives. Strong cooperative willingness could spur enthusiasm for investment, increase knowledge exchange and sharing, induce knowledge collaboration and creation, as well as enhance cooperative profit. With cooperation strengthening, organization matchup among partners would improve continuously so as to generate mutual cooperative willingness and targets. This mutual benefit would trigger optimal knowledge collaboration. Therefore, R&D and innovation potentials, culture compatibility, cooperative willingness and organizational matchup have positive effect on credibility maintenance and knowledge collaboration in R&D cooperation in the aspect of cooperative potential.

Above all, based on domestic and overseas studies on credibility among enterprise and supply chain partners (Wang et al., 2009; Das and Teng, 2001; Cheng et al., 2014), this study establishes an evaluation index system in four aspects of social environment collaboration, partner collaboration, partnership collaboration and cooperative potential collaboration, as shown in **Table 1**.

Dynamic Evaluation Model on Credibility of High-tech Enterprise Partners in Knowledge Collaboration

High-tech enterprise partners' credibility evaluation index weight measurement

Considering the subjectivity of indexes for evaluating credibility of high-tech enterprise partners, expert consultation shall be adopted to assess index criticality. In this paper, the Delphi method is employed to settle influential degrees of various indexes on credibility. An expert consultation questionnaire about index incidences on partner credibility has been designed with five scales, that is, Level 1-5. Specifically, incidences of index e_x are regarded as "very high", "high", "moderate", "low" and "very low", scoring 5, 4, 3, 2 and 1 respectively.

$$f_x = \begin{cases} 4, & when\ 2/3 or\ more\ experts\ stand\ for\ e_x \geq 4 \\ 3, & when\ 1/3 - 2/3 experts\ stand\ for\ e_x \geq 4 \\ 2, & when\ 0 - 1/3 experts\ stand\ for\ e_x \geq 4 \\ 1, & when\ no\ experts\ tands\ for\ e_x < 4 \end{cases} \quad (1)$$

In Formula (1), e_x refers to expert scoring on the x th index, $e_x \in [1,5]$, integers; while f_x refers to the x th index's incidence on credibility.

Index weight W_x could be achieved through normalization processing on f_x acquired in Formula (1):

$$W_x = f_x / \sum_{x=1}^{n} f_x \quad (x = 1,2, \dots, n) \quad (2)$$

High-tech enterprise partners' credibility evaluation methodology selection

In this paper, Set Pair Analysis and Markov Chain have been adopted to evaluate credibility of high-tech enterprise partners in knowledge collaboration. Specifically, Set Pair Analysis is taken to calculate connection degree of partner trust, reflect credibility, as well as reveal dynamic trend of credibility in combination with equal power, balance power and opposite power in connection degree. Markov Chain forecasts connection degree of next period based on that of previous month via identity-discrepancy-contrary (IDC) transition matrix between the two months. A combination of Set Pair Analysis and Markov Chain could dynamically assess credibility of high-tech enterprise partners in knowledge collaboration. Based on the tendency reflected in dynamic evaluation results, steady evaluation results on credibility would be figured out. Accordingly, the credibility is assessed more objectively and thoroughly, which benefits cooperative strategy adjustment and risk reduction.

(1) Set Pair Analysis

The Set Pair Analysis (SPA), put forward by Chinese scholar Zhao in 1989, is a systemic analysis method aimed at IDC quantitative inference on system. It has been extensively applied in the fields covering scientific research, engineering technology, modern management, fuzzy mathematics, artificial intelligence and social economy (Hu et al., 2008). The basic idea lies in analyzing features of a set pair from three perspectives (identity, discrepancy and contrary) under some certain topic. That is to say, analyze which features of the two sets are common, which are opposite, and which else are neither the same nor the opposite (Koufaris and Hampton-Sosa, 2004). On this basis, the IDC connection degree could be presented as (Song and Xu, 2009; Jing et al., 2013):

$$\mu = \frac{S}{N} + \frac{F}{N} i + \frac{R}{N} j \quad (3)$$

In Formula (3), μ refers to IDC connection degree; N represents total features of set pair; S stands for total common features in the set pair, R for total opposite features and F for total features neither identical nor opposite. $F = N - S - R$. Meanwhile, i marks discrepancy degree, $i \in [-1,1]$; while l signals contrary degree, $j = -1$ in general. Supposing that identity, discrepancy and contrary are expressed as $a = S/N$, $b = F/N$ and $c = R/N$ respectively, then Formula (3) could be:

$$\mu = a + bi + cj \quad (4)$$

In Formula (4), a, b and c are real numbers, $a, b, c \in [0,1]$ and $a + b + c = 1$.

Considering different contributions of each feature, ratios between IDC amounts and total amount could not be simply regarded as coefficients of identity, discrepancy and contrary. Instead, their weights shall be taken into consideration; w_k ($k = 1,2, \dots, N$; $\sum_{k=1}^{N} w_k = 1$). Accordingly, the set pair connection degree mentioned above could be demonstrated as (Jing et al., 2013):

$$\mu = a + bi + cj = \sum_{k=1}^{S} w_k + \sum_{k=S+1}^{S+F} w_k i + \sum_{k=S+F+1}^{N} w_k j \quad (5)$$

(2) Markov Chain

Static analysis on research objects as SPA makes, it fails to conduct assessment dynamically. As all matters change with time, Markov Chain (MC) shall be combined for implementing dynamic evaluation after concept of time is introduced. The MC, as a theory on system conditions and transfers, settles variation trend through exploring initial probabilities of different states and transition probabilities between states; therefore future trend is predicted (Jia and Du, 2011; Shi et al., 2014).

Considering $C(t)$, $t \in T$ as a random process, observed values $C_1, C_2, \dots, C_m$ on $C(t)$at moments of $t_1, t_2, \dots, t_m$ ($t_1 < t_2 < \cdots < t_m \in T$) would meet the conditions of (Zhou et al., 2013):

$$P(C_m|C_{m-1}, C_{m-2}, \dots, C_1) = P(C_m|C_{m-1}) \quad (6)$$

Formula (6) demonstrates the Markov process, indicating that random process value at the moment of t_m is merely related with the value at t_{m-1}, but not values at previous moments. $P(C_m|C_{m-1})$ refers to transition probability. The Markov process shall be considered as MC when timing is discrete and research objects perform discretely over time (Shi et al., 2014). Evaluation on credibility of high-tech enterprise partners varies discretely over time; correspondingly, MC is combined in this paper for dynamic assessment.

SPA-Markov-based dynamic evaluation model

Credibility measurement for high-tech enterprise partners in knowledge collaboration is dynamic as influential factors vary with time. Supposing that there exist S_t features in identity, F_t features in discrepancy and R_t features in contrary at the moment of t with $S_t + F_t + R_t = N$, then feature weights at t shall be $w_i (i = 1,2, \dots, N;\ \sum_{i=1}^{N} w_i = 1)$ and connection degree at t shall be (Song and Xu, 2009):

$$\mu(t) = a(t) + b(t)i + c(t)j = \sum_{k=1}^{S_t} w_k(t) + \sum_{k=S_t+1}^{S_t+F_t} w_k(t)i + \sum_{k=S_t+F_t+1}^{N} w_k(t)j \quad (7)$$

In Formula (7), $\sum_{k=1}^{S_t} w_k(t) + \sum_{k=S_t+1}^{S_t+F_t} w_k(t) + \sum_{k=S_t+F_t+1}^{N} w_k(t) = 1$.

During the period $[t, t+T]$, values of influential factors on credibility have changed over time. Provided that S_{t1} of S_t features remains in identity at the moment of $t + T$, while S_{t2} features change into discrepancy and S_{t3} into contrary, with $S_{t1} + S_{t2} + S_{t3} = S_t$, then the transfer vector of S_t during $[t, t+T]$ shall be:

$$S = (P_{11}, P_{12}, P_{13}) = [\sum_{k=1}^{S_{t1}} w_k(t), \sum_{k=S_{t1}+1}^{S_{t1}+S_{t2}} w_k(t), \sum_{k=S_{t1}+S_{t2}+1}^{S_t} w_k(t)]/\alpha(t) \quad (8)$$

In Formula (8), $P_{11} + P_{12} + P_{13} = 1$, $\alpha(t) = \sum_{k=1}^{S_t} w_k(t)$.

Similarly, the transfer vector of F_t during $[t, t+T]$ shall be:

$$F = (P_{21}, P_{22}, P_{23}) = [\sum_{k=S_{t1}+1}^{S_t+F_{t1}} w_k(t), \sum_{k=S_t+F_{t1}+1}^{S_t+F_{t1}+F_{t2}} w_k(t), \sum_{k=S_t+F_{t1}+F_{t2}+1}^{S_t+F_t} w_k(t)]/\beta(t) \quad (9)$$

In Formula (9), $P_{21} + P_{22} + P_{23} = 1$, $F_{t1} + F_{t2} + F_{t3} = F_t$, $\beta(t) = \sum_{k=S_t+1}^{S_t+F_t} w_k(t)$.

The transfer vector of R_t during $[t, t+T]$ shall be:

$$R = (P_{31}, P_{32}, P_{33}) = [\sum_{k=S_t+F_t+1}^{S_t+F_t+R_{t1}} w_k(t), \sum_{k=S_t+F_t+R_{t1}+1}^{S_t+F_t+R_{t1}+R_{t2}} w_k(t), \sum_{k=S_t+F_t+R_{t1}+R_{t2}+1}^{N} w_k(t)]/\gamma(t) \quad (10)$$

In Formula (10), $P_{31} + P_{32} + P_{33} = 1$, $R_{t1} + R_{t2} + R_{t3} = R_t$, $S_t + F_t + R_t = N$, $\gamma(t) = \sum_{k=S_t+F_t+1}^{N} w_k(t)$.

As a result, the IDC transition matrix during $[t, t+T]$ shall stand at (Shi et al., 2014):

$$D = \begin{bmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{bmatrix} \quad (11)$$

As the moment of $t + T$, the connection degree$\mu(t+T)$ of set pair shall be presented as (Hu et al., 2008):

$$\begin{aligned} \mu(t+T) &= a(t+T) + b(t+T)i + c(t+T)j \\ &= [a(t+T), b(t+T), c(t+T)] \cdot D \cdot (1, i, j)^T \end{aligned} \quad (12)$$

On condition that transition matrix stays the same in each variation period (in other words, the transition matrix M is a constant matrix), then the connection degree after n periods shall stand as (Hu et al., 2008):

$$\begin{aligned} \mu(t+nT) &= a(t+nT) + b(t+nT)i + c(t+nT)j \\ &= [a(t+T), b(t+T), c(t+T)] \cdot D^{nT} \cdot (1, i, j)^T \end{aligned} \quad (13)$$

Table 2. Index weight and credibility grade variation in 12 months

Primary Index	Secondary Index	Index Weight	Period (Month)											
			1	2	3	4	5	6	7	8	9	10	11	12
Social environment collaboration	Market uncertainty	0.045	H	G	G	L	G	H	G	L	H	H	L	G
	Government support	0.068	G	H	H	G	L	L	G	H	L	G	H	H
	Legal guarantee	0.023	L	G	G	H	G	L	G	H	L	G	G	H
Partner collaboration	R&D competence	0.091	H	G	L	L	G	H	H	L	G	G	H	H
	Entrepreneurial ability	0.045	G	G	G	H	L	H	H	L	L	G	G	G
	Reputation	0.091	H	H	G	L	G	H	H	G	L	L	G	G
	Cooperation experience	0.068	L	L	G	H	H	L	G	G	H	L	H	G
Cooperative relationship collaboration	Communication	0.070	G	L	G	G	H	H	L	G	H	H	G	H
	Promise	0.068	H	H	L	G	G	G	H	H	L	L	L	G
	Dependency	0.045	G	G	L	G	H	L	H	G	G	G	L	L
	Sharing	0.091	H	H	L	H	L	G	H	G	H	L	H	L
	Conflict resolution mechanism	0.023	L	G	L	L	H	G	H	H	G	L	L	G
Cooperative potential collaboration	R&D and innovation potentials	0.068	L	G	G	H	L	H	L	H	H	G	L	G
	Culture compatibility	0.045	G	H	H	H	L	G	H	L	G	H	H	G
	Cooperative willingness	0.091	H	H	H	L	G	L	G	H	G	H	L	G
	Organizational matchup	0.068	G	H	G	L	G	H	H	G	L	H	G	H

D^{nT} tends to be steady over time. The connection degree at the moment of t would stabilize over time until a steady connection degree μ is concluded as (Shi et al., 2014):

$$\begin{cases}(abc)\cdot(\boldsymbol{E}-\boldsymbol{D})=\boldsymbol{0}\\ a+b+c=1\end{cases} \tag{14}$$

In Formula (14), E stands for unit matrix.

RESULTS ANALYSIS AND DISCUSSION

Credibility of high-tech enterprise partners in knowledge collaboration is graded as H, G and L, representing high credibility, general credibility and low credibility respectively. With the cooperative partner HS of China FAW Tooling Die Manufacturing Co. LTD as an example (because the relevant information of the high-tech enterprise partner in the example belongs to the internal information, which is inconvenient for being revealed, the partner name is represented by HS), the dynamic changes of credibility of the partner HS in 1 year of cooperation time is observed to verify the feasibility of credibility dynamic evaluation of high-tech enterprise partners in R&D with the set pair analysis and Markov chain model. As the high-tech enterprise producing auto body mold and welding fixture, China FAW Die Manufacturing Co. Ltd. is currently the leading enterprise with the most advanced technology and the most core competitiveness in the industry of China auto body mold and welding fixture. Partner HS is a high-tech enterprise of machinery and industry equipment, with the main business involving the design and production of aircraft and auto jigs and fixtures, and has established a strategic partnership with China FAW Tooling Die Manufacturing Co. LTD to design and develop tooling equipment such as molds and fixtures jointly. In the paper, the credibility of the cooperative partner HS of China FAW Tooling Die Manufacturing Co. LTD is reflected dynamically in line with twelve months of the year (See **Table 2**).

Dynamic assessment is made on credibility of high-tech enterprise partners in knowledge collaboration based on connection degree coefficients. As to the connection degree of $\mu = a + bi + cj$, on condition of $c \neq 0$, equal power, balance power and opposite power would be attainted with $a > c$, $a = c$ and $a < c$ respectively (Wang et al., 2006). Specific trends are demonstrated in **Table 3**.

Based on influential indexes in **Table 1**, questionnaire has been designed for expert consultation; through network search and using social networks, professors in the field of innovation management of Harbin Engineering University and Harbin Institute of Technology, as well as the middle-senior managers attending the EMBA training in Harbin Engineering University or of the high-tech enterprises having cooperative programs with Harbin Engineering University were consulted via field visit, telephone or email. A total of 30 questionnaires have been delivered, and the effective recovery totals 30, equivalent to a usable response rate of 100%.

Based on the data from questionnaires, index weights have been worked out via Formula (1) and Formula (2) as shown in **Table 2**.

Table 3. Variation trend of high-tech enterprise partner credibility (Koufaris and Hampton-Sosa, 2004)

Set Pair Potential	Comparison on H, G and L	Variation Trend	Credibility
Equal power (H>L)	H>L, H>G, G>L	Very strong identity	Trustworthy
	H>L, H>G, G=L	Strong identity	Trustworthy
	H>L, H>G, G<L	Moderate identity	Trustworthy
	H>L, H=G, G>L	Weak identity	Moderately trustworthy
	H>L, H<G, G>L	Very weak identity	Moderately trustworthy
Balance power (H=L)	H=L, H>G, G<L	Strong balance of identity and opposite	Moderately trustworthy
	H=L, H=G, G=L	Balance among trends	Moderately trustworthy
	H=L, H<G, G>L	Weak balance of identity and opposite	Untrustworthy
Opposite power (H<L)	H<L, H>G, G<L	Very strong opposite	Untrustworthy
	H<L, H=G, G<L	Strong opposite	Untrustworthy
	H<L, H<G, G<L	Moderate opposite	Untrustworthy
	H<L, H<G, G=L	Weak opposite	Untrustworthy
	H<L, H<G, G>L	Very weak opposite	Untrustworthy

Figure 2. Dynamic variations of partner credibility in one year

On this basis, SPA-Markov Model is adopted to dynamically analyze the credibility of the cooperative partner HS of China FAW Tooling Die Manufacturing Co. LTD. Firstly, the assessing connection degree of credibility of cooperative partner HS for each month is acquired through Formula (7):

$$\mu_1 = 0.477 + 0.341i + 0.182j, \quad \mu_2 = 0.522 + 0.340i + 0.138j, \quad \mu_3 = 0.204 + 0.478i + 0.318j$$

$$\mu_4 = 0.340 + 0.251i + 0.409j, \quad \mu_5 = 0.206 + 0.477i + 0.317j, \quad \mu_6 = 0.478 + 0.227i + 0.295j$$

$$\mu_7 = 0.567 + 0.295i + 0.138j, \quad \mu_8 = 0.341 + 0.433i + 0.226j, \quad \mu_9 = 0.342 + 0.295i + 0.363j$$

$$\mu_{10} = 0.319 + 0.340i + 0.341j, \quad \mu_{11} = 0.363 + 0.297i + 0.340j, \quad \mu_{12} = 0.320 + 0.544i + 0.136j$$

When comparing the credibility connection degrees of the cooperative partner HS in twelve months with the dynamic tendency information in **Table 3** in the example, it can be found that HS is trustworthy in the 1st, 2nd, 6th, 7th and 11th months, moderately trustworthy in the 8th and 12th months, but untrustworthy in the 3rd, 4th, 5th, 9th and 10th months, and specific trend is illustrated in **Figure 2**. According to **Figure 2** and consultations to management staff in China FAW Tooling Die Manufacturing Co. LTD., HS has held relatively weak credibility. Despite trustful in the beginning of cooperation, it behaved speculatively as time went on, dragging down its credibility sharply. In response, China FAW Tooling Die Manufacturing Co. LTD. carried out a series of relationship governance mechanism (like organizing forums and exchanges, formulating reward and punishment measures, as well as dispatching staff to the partner site for supervision), which helped to raise the partner's credibility. However, the governance eased along with uptick in credibility, which later resulted in gradually weakening trust in demand for enterprise governance again. Above all, through one-year dynamic evaluation on HS's credibility, HS has been regarded opportunistically in cooperation. This requires the enterprise to work out governance mechanism to stimulate and restrict its partner in cooperation. If necessary, cooperation could be ended promptly to avoid squander in R&D innovative resources and the loss of the interests of the enterprise.

IDC transition matrixes $D_{12}, D_{23}, \ldots, D_{1112}$ for between months are acquired through calculations via Formula (8)-(10). On condition of same weight for these matrixes, an average matrix D is obtained as follows:

$$D_{12}=\begin{bmatrix}0.715 & 0.285 & 0\\ 0.264 & 0.531 & 0.205\\ 0.374 & 0.626 & 0\end{bmatrix},\quad D_{23}=\begin{bmatrix}0.391 & 0.305 & 0.304\\ 0.532 & 0 & 0.468\\ 0 & 0 & 1\end{bmatrix},\quad D_{34}=\begin{bmatrix}0.221 & 0.333 & 0.446\\ 0.146 & 0.427 & 0.427\\ 0.358 & 0.356 & 0.286\end{bmatrix}$$

$$D_{45}=\begin{bmatrix}0.200 & 0.068 & 0.732\\ 0.271 & 0.458 & 0.271\\ 0 & 0.944 & 0.056\end{bmatrix},\quad D_{56}=\begin{bmatrix}0.340 & 0.112 & 0.548\\ 0.143 & 0.618 & 0.239\\ 0.215 & 0.429 & 0.356\end{bmatrix},\quad D_{67}=\begin{bmatrix}0.617 & 0.094 & 0.289\\ 0 & 1 & 0\\ 0 & 0.847 & 0.153\end{bmatrix}$$

$$D_{78}=\begin{bmatrix}0.161 & 0.520 & 0.319\\ 0.231 & 0.617 & 0.152\\ 0 & 0.507 & 0.493\end{bmatrix},\quad D_{89}=\begin{bmatrix}0.199 & 0.334 & 0.466\\ 0.104 & 0.529 & 0.367\\ 0.199 & 0.602 & 0.199\end{bmatrix},\quad D_{910}=\begin{bmatrix}0.336 & 0.199 & 0.465\\ 0.461 & 0.461 & 0.078\\ 0.438 & 0.375 & 0.187\end{bmatrix}$$

$$D_{1011}=\begin{bmatrix}0.141 & 0.433 & 0.426\\ 0.200 & 0.468 & 0.332\\ 0.267 & 0.267 & 0.466\end{bmatrix},\quad D_{1112}=\begin{bmatrix}0.438 & 0.311 & 0.251\\ 0.458 & 0.542 & 0\\ 0.132 & 0.868 & 0\end{bmatrix},\quad D=\begin{bmatrix}0.342 & 0.272 & 0.386\\ 0.255 & 0.514 & 0.231\\ 0.180 & 0.529 & 0.291\end{bmatrix}$$

Based on $\mu_1, \mu_2, \ldots, \mu_{12}$ acquired above, the partner's average connection degree among twelve months shall be $\bar{\mu} = 0.373 + 0.360i + 0.267j$.

Then, according to HS's average connection degrees among 12 months, connection degrees for the beginning of the next year could be predicted via Formula (12), enabling the enterprise to judge whether to continue this partnership with HS. The connection degree for the first month of the next year shall be:

$$\mu_{13} = \bar{\mu} \cdot D = (0.373, 0.360, 0.267) \cdot D \cdot (1, i, j)^T = 0.267 + 0.428i + 0.305j$$

According to **Table 3**, it could be forecasted that HS might be untrust worthy next year, and it might have opportunistic behaviors in cooperation, which would affect the trust relationship between each other, but according to the dynamic change trend of credibility in the table, the trend that its credibility would develop worse is weak. In view of this, the enterprise shall concentrate on the partner's cooperative tendency as well as take timely and rational measures to coordinate the partnership with HS in case of cooperation profit losses.

The predicted credibility of HS for the first month next year, despite reflecting the variation trend of the credibility of HS to some extent, fails to reveal a stable credibility of HS thoroughly. Correspondingly, Formula (13) and (14) shall be adopted to acquire steady connection degree of HS. In event that the transition matrix D stays unchanged, the credibility of HS is evaluated periodically, and after a period of governance, the steady connection degree reflecting HS's final credibility can be obtained as follows:

$$\begin{cases}(\hat{H}, \hat{G}, \hat{L}) \cdot \begin{bmatrix}0.658 & -0.272 & -0.386\\ -0.255 & 0.486 & -0.231\\ -0.180 & -0.529 & 0.709\end{bmatrix} = \mathbf{0}\\ \hat{H} + \hat{G} + \hat{L} = 1\end{cases}$$

According to the above equations, $\hat{H} = 0.256$, $\hat{G} = 0.456$ and $\hat{L} = 0.288$. Correspondingly, the steady connection degree shall be $\hat{\mu} = 0.256 + 0.456i + 0.288j$.

According to the steady connection degree $\hat{\mu}$, $\hat{H} < \hat{L}$, $\hat{H} < \hat{G}$, $\hat{G} > \hat{L}$. It could be concluded from **Table 3** that the dynamic change trend of credibility of HS, the cooperative partner of China FAW Tooling Die Manufacturing Co. LTD., is: the opposition is the main, the degree of opposition is weak, and it is not worthy of trust. In view of this, according to **Figure 3** and steady connection degree, it can be found that the credibility of HS is sometimes good and sometimes bad with frequent fluctuations, and its credibility is probably to weaken in the future, indicating that HS has opportunistic behaviors in cooperation, and there is an unstable cooperation tendency, which will harm the interests of other partners, and it is generally considered to be unworthy of trust; however the degree of opposition of HS is weak, indicating that the trend that its credibility would develop worse is weak, in other words, if its unstable tendency is eliminated in time, the credibility of HS might evolve to the beneficial direction, so the enterprise need to set up effective governance mechanism to maintain the trust relationship according to the performance of HS in the cooperation: if the credibility of HS is improved in the process of governance, the enterprise can continue to cooperate with it, otherwise, the enterprises could restrict it or even terminate cooperation with it so as to reduce the risk of cooperation.

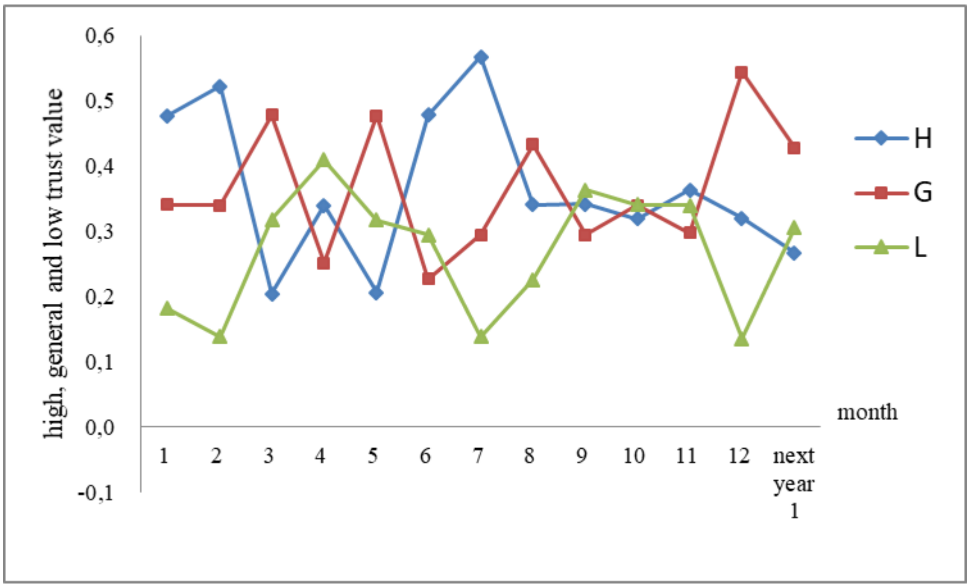

Figure 3. Dynamic changes and trends of HS credibility

CONCLUSION

Considering high risks and uncertainty in high-tech enterprise collaborative innovation, SPA-Markov dynamic evaluation model has been established in this paper for precisely assessing credibility of high-tech enterprise partners and making up with disadvantages of traditional static judgment. China's FAW Tooling Die Manufacturing Co., Ltd and its partner HS has been case-studied to prove the model's feasibility. Conclusions are drawn as follows:

(1) The SPA-Markov dynamic evaluation model covers the process of partners achieving balance, which could not be involved in traditional static assessment. Accordingly, it directly reflects strategic collaborations between high-tech enterprises and their partners.

(2) The model could clearly demonstrate uncertainty of collaborative behaviors adopted by high-tech enterprise R&D partners. The behaviors might fluctuate over time driven by benefits. As a result, the model provides technological support for high-tech enterprises in selecting correct partners.

(3) The model could effectively predict the trend of high-tech enterprise partners' credibility, which enables high-tech enterprises to make objective and thorough evaluation on their partners.

Above all, a combination of SPA and Markov Chain has capacitated dynamic, continuous assessment on partner credibility, as well as objectively reflected credibility conditions in different periods. It benefits judging trustworthiness of partners in cooperation and discovering opportunistic behavior timely so that effective measures could be taken to reduce risks. The model, easy in calculation and operation as well as reliable in results, could make real and overall measurement of dynamic situation and future trend.

Significant as SPV-Markov Model has been employed for dynamic evaluating credibility of high-tech enterprise partners, the evaluation index system has been settled through literature extraction and law relationship, lacking expert consultations or practical investigations including trust mechanism explorations through discourse analysis, grounded theory and scenario analysis. Accordingly, further study is expected in this direction so as to achieve more effective correspondence between theoretical and practical significances.

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