Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 13 (20): 4181-4187, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.4181.4187

Knowledge Networks Formation and Interchain Coupling of Knowledge Chains

[1]Qifeng Wei and [1,2]Xin Gu
[1]Business School,
[2]Institute for Innovation and Entrepreneurial Management, Sichuan University,
Chengdu, 610064, China

Abstract: The issue of Knowledge Networks (KN) formation has been frequently discussed, but no acknowledged results have been reached yet. The study analyzes the formation mechanism of knowledge networks from the perspective of interchain coupling, aiming to find out the essence of KN formation. Specifically, the article proposes a KN structural framework and it studies KN's coupling subjects, relationships and types. In addition, it uses Hamiltonian function in quantum mechanics to simulate the operation of knowledge chains in KN, the types of which can be divided into 'coupling-free knowledge chain', 'uni-coupling knowledge chain' and 'multi-coupling knowledge chain'. Then it carries out a mathematical deduction on the formation mechanism of three types of interchain coupling of knowledge chains for KN. A conclusion can be drawn that interchain coupling of knowledge chains is the essential reason of KN formation and there are also three types of interchain coupling, which reflects the diversity of cooperation in KN.

Key words: Coupling, knowledge vertex, knowledge chain, knowledge network

INTRODUCTION

With the deepening of economic globalization and knowledge economy tendency, innovation has developed from the early simple linear model to the complex interaction model, for example, innovation is created through the complex network constituted and interacted by a number of factors (Rothwell, 1992). Enterprises have paid more attention to the agglomeration between companies and within the company and established contact with other organizations such as suppliers, customers, service agencies, government, universities, research institutes, etc., in order to achieve continuous innovation. According to a statistical study from Becheikh *et al*. (2006), networks are positive to the most impacts on innovation. The existence of the network can be significantly enhanced employee loyalty and satisfaction, rely on knowledge reuse to improve efficiency and to promote innovation with knowledge leverage (Buchel and Raub, 2002). Integrating external knowledge and other resources by relying on the network has become the key to innovative formation, development and success, which promotes the formation of KN to a great extent (Liu *et al.*, 2013). With the advancement of innovative theoretical and practical work, innovative behaviors are increasingly complex and showing the characteristics of the network and the innovative theoretical research focus has gradually shifted to the networks. However, issues on the formation of KN are still confusing, it is highly necessary to make a study, to find out the essential reason of KN formation for the further research, which is precisely the goal of the article.

FORMATION OF KNOWLEDGE NETWORKS

The earliest knowledge network was proposed by the Swedish industry, the concept was used to describe the institutions and activities of those engaged in the production and dissemination of scientific knowledge. Many research institutions and scholars gave their definitions thereafter, some considers that knowledge network is a dynamic framework constituted by actors, the relationship between them, the use of resources in the relationship and its system features (Seufert *et al.*, 1999) and is a network formed by connection of knowledge subjects such as people and businesses (Jarvenpaa and Tanriverdi, 2003) and is the sum of formal and informal relationships which are relatively stable and can facilitate knowledge transfer (Cappellin and Wink, 2009). Forming subjects of knowledge networks topology are also hierarchical (Phelps *et al.*, 2012). As a complex system, knowledge network is exchanging matter and energy (knowledge and information) with the outside and connection relations between numbers of vertexes and vertexes themselves are dynamically evolving, along with the internal and external energy exchange of the system.

Corresponding Author: Xin Gu, Business School, Sichuan University, Chengdu, 610064, China

In addition, there is a complex embedding relationship between knowledge networks and other types of networks such as social networks, interpersonal networks.

As Nowak (2006) considers, spatial structure and social networks have enhanced the interaction between the individual, the formation of the network reciprocity effect is one of the five important principles to explain cooperation formation. Behavior of knowledge complementary is the motivation of knowledge network formation and these organizations involved in the operation of the network have scarce knowledge of other organizations (Carayanni and Alexander, 1999). Embedding of cognitive, relation and structure has big effects on the main bilateral cooperation validity, the collaborative innovation results are derived from the heterogeneous knowledge restructuring between cooperation members and the success of cooperation depends on the inter-organizational knowledge complementarity (Cowan *et al*., 2007).

In addition, proximity of cognitive level, social contact and geographical distance is an important factor in the formation of knowledge networks (Broekel and Boschma, 2012), the physical distance between the relative position of the vertexes in the network has a very significant impact on the knowledge creation, e.g., geographical proximity (Owen-Smith and Powell, 2004). Social proximity is rooted in a social relationship, which promotes the formation of knowledge networks by using trust as the intermediary (Boschma, 2005). And it is easier for companies to imitate behaviors in the strategic choice and operation of enterprises with similar organizational structure (Guler *et al*., 2002). Knowledge network from scratch along with the knowledge transformation process between knowledge vertexes, covering the whole dynamic logic process of knowledge creation, aggregation, diffusion, transfer, learning and absorption, in the process of knowledge flows, the link between vertexes emerges, from sparse to dense and gradually grows into a knowledge network (Fig. 1). What Anderson stated is we can understand the organization's networking process from two aspects of external form and internal relations (Anderson, 1999). Knowledge network formation process in a certain sense refers to the process of the emergence of the structural characteristics of the knowledge network and what usually used to measure the characteristics of the network structure indicators includes the degree correlation coefficient, network clustering coefficient, degree distribution, correlation coefficient of local aggregation and the average shortest distance, etc. (Newman, 2003) and change of contents of the knowledge network formation process is mainly reflected in the knowledge inventory changes, as well as knowledge flow rate and amount, etc. (Sorenson *et al*., 2006).

Knowledge network formation process is a complex dynamic process, the researchers were unable yet to agree on principles and process mechanism for the formation of knowledge networks, but the judgment 'the knowledge network is constituted by many knowledge vertexes (or subjects) under the influence of some mechanism' is unified, which can be explained by game theory, resource dependence theory, transaction cost theory, theory of core competence, etc. Unfortunately, these theories are concentrated on the individual level, ignoring the interaction mechanism of clusters and whose impact on the macro-knowledge network complexity. The study argues that the formation of knowledge networks is resulting from the interchain coupling of knowledge chains.

INTERCHAIN COUPLING OF KNOWLEDGE CHAINS FOR KNOWLEDGE NETWORKS

Coupling is from physics, refers to a phenomenon that two or more systems or motions interact to unite, it's a kind of interdependent, coordinated and mutually reinforcing dynamic relationship formed through the positive interaction between the various subsystems.

Knowledge chain renders as a chain structure, which considers enterprises as its core subjects of innovation, takes the knowledge sharing and knowledge creation as

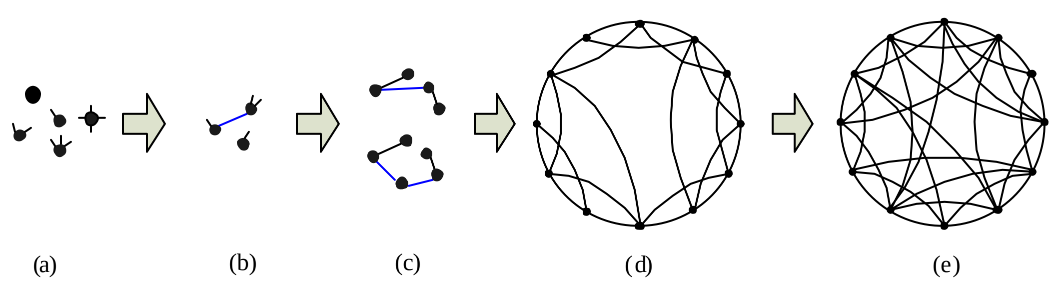

Fig. 1(a-e): Formation of network structure (a) Multiple independent vertexes, (b) Link emerges between vertexes, (c) Link emerges between chains, (d) Sparse network and (e) Dense network its aim and is formed by the knowledge flow between the different organizations involved in innovation activities. Evidently, knowledge chain is formed by knowledge vertexes coupling and knowledge network is formed by interchain coupling of knowledge chains, therein, a non-linear structural link is formed between the knowledge chains, including coordination, conflict links and finally promotes the formation of knowledge networks.

Coupling subjects

Coupling of knowledge vertexes: Enterprises, universities, research institutes, as well as some of the knowledge service-oriented agencies are materialized forms of knowledge vertexes, on the basis of cognitive level, social ties, organizational structure similarity and synergistic of each knowledge vertex, they are coupling and forming a chained knowledge-rich organizations with special functions, i.e., knowledge chain:

- **Interactive learning:** A certain level of interactive learning is the premise and maintaining momentum of the formation of the coupling relationship between knowledge vertexes, which is a complex process of organizational level actors. Along with the continuous knowledge flow, knowledge stock increased, knowledge transfer channels and forms constantly improved, the knowledge flow scale gradually expanded and the robustness of coupling relationship is also enhanced
- **Mutual trust:** The establishment of trust mechanism between vertexes is the protection of the strong coupling relationship. The generating of trust is based on the strong ties between vertexes and establishment of continuing reciprocity norm (Nowak, 2006) and strong ties are gradually formed in the understanding and observation on each other's behavior
- **Cooperative game:** The coupling relationship between knowledge vertexes is the result of cooperative game. The benefits distribution mechanism among the knowledge vertexes has direct impact on the knowledge chain stability and continuity. Coupling link between different knowledge vertexes is based on the pursuit of common interests and the unity of profit motive, various vertexes form the knowledge chain of resource sharing and advantage complementary by means of the system self-organization process, realizing behavior collaboration, institutional collaboration and knowledge collaboration, to achieve the Pareto optimal under the collective rationality cooperation

Interchain coupling of knowledge chains: Complex correlation between heterogeneous knowledge is the essential cause that the knowledge chains forms the crisscross knowledge networks, meanwhile, the emergence of complex system characteristics of knowledge networks is also from the distributed complex relevance among various knowledge vertexes which belong to different knowledge chains. The interchain coupling of knowledge chains is the direct cause for the formation of knowledge network:

- **Knowledge similarity principle:** The existence of heterogeneous knowledge provides a potential opportunity for cooperation of different knowledge chains, but also builds barriers that prevent smooth cooperation to some extent; however, if the knowledge between the knowledge chains is too similar, knowledge flow will cease, for the coupling value of demand for complementary knowledge has disappeared
- **Diversity of coupling relations:** The diversity of coupling relations among knowledge chains is derived from the multiple types of knowledge as well as the organizational attributes difference of knowledge subjects. First, knowledge-based enterprise is the core subject of knowledge chain, which has the advantage of knowledge in the field of specific industry and the remaining component units also have the homogeneity knowledge. Meanwhile, due to that the knowledge subjects have special knowledge details and their abilities belong to different areas of action, the link between the knowledge subjects that belong to different knowledge chains is three-dimensional and diversified, which exactly formed the complex coupling interaction. In addition, the diversity on structural attributes, functional attributes, cultural attributes, target attributes, geographical attributes and social attributes of knowledge subject itself are also contributed to the diversity of coupling relations Fig. 2
- **Diversity of coupling types:** Interchain coupling of knowledge chains is forming based on the overall knowledge potential energy gap, for two knowledge chains whose overall knowledge potential energy are almost equal, the coupling is impossible to happen. Besides, for those knowledge chains having knowledge potential energy gap, gaps on knowledge attributes and abilities of knowledge vertexes result in the different types of relations between heterogeneous knowledge chains. From realistic situations, interchain types of coupling generally

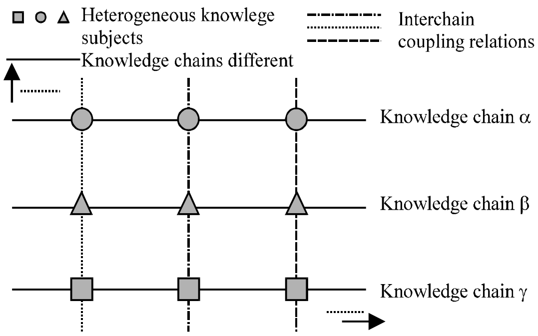

Fig. 2: Diversity of coupling relations in knowledge networks

include ‘coupling-free’, ‘uni-coupling’ and ‘multi-coupling’. The study carries out a mathematical analysis on these three interchain types to study how they are relatively coupled

METHODOLOGY

In order to visually reflect the interchain coupling of knowledge chains, this study uses Hamiltonian function in quantum mechanics to replace the expression of the knowledge stock of the knowledge chain and chooses Wang’s coupled parallel chains model (Wang, 1993) to simulate the operation of knowledge chains in knowledge networks.

Assume that there are two knowledge chains: α and β, interchain coupling is completed by the interaction among knowledge vertexes in two knowledge chains, which is similar to wave function superimposition of diatomic molecules at the same level.

MATHEMATICAL ANALYSIS ON THE INTERCHAIN COUPLING PROCESS

Generally, the types of knowledge chains in the knowledge networks can be divided into ‘coupling-free knowledge chain’, ‘uni-coupling knowledge chain’ and ‘multi-coupling knowledge chain’ (Fig. 3).

Coupling-free: For the one-dimensional knowledge chain, its tight-binding Hamiltonian is:

$$g(i, j, Z) = <I|g(Z)|\, j> = g^{ij} \quad (1)$$

$$k) = \sum_j \frac{1}{\sqrt{N}} e^{-ika} \, | j > \quad (2)$$

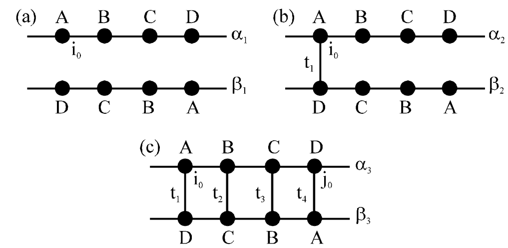

Fig. 3: Three types of knowledge chains coupling

here |i> is the grid point state, |k) is the Bloch state, a is the lattice constant, j-th refers to the j-th position of grid point, there is no post-election among different grid point state:

$$<I|j> = \delta_{ij} \quad (3)$$

the energy spectrum of |k) is:

$$E(k) = \varepsilon + 2t \cos ka \quad (4)$$

the Green function is:

$$g(Z) = \frac{1}{Z-H} = \sum_k \frac{|k)(k|}{Z-E(k)} = \sum_{ij} g^{ij} |i><j| \quad (5)$$

Then:

$$g^{ij} = \sum_k \frac{e^{[ika(i-j)]}}{Z-E(k)} \quad (6)$$

Non-diagonal matrix element is:

$$g(i, j, Z) = <i|g(Z)|j> = g^{ij} \quad (7)$$

that is the probability of knowledge flow from grid point i to grid point j and the diagonal matrix element is:

$$g(i, j, Z) = g^{ij} = g_0 \quad (8)$$

it’s the green function of grid point i, its grid state density of the imaginary part is expressed as:

$$g_0 = \pm \frac{1}{\sqrt{(Z-\varepsilon)^2 - 4t^2}} \quad (9)$$

$$g^{ij} = g_0 \rho^{|i-j|}{}_{min} \quad (10)$$

And ρ_{min} refers to take the root of $\rho_{min}<1$ in ρ^2-2xρ+1 = 0, x = (Z-ε)|2t, ± in g_0, respectively corresponding to ∓ in $\rho = x \mp \sqrt{x^2-1}$. Equation 10 means that the probability of knowledge flow from grid point i to grid point j and from j to i are fairly equal.

The Hamiltonian of system consisting of α and β is:

$$H_0 = H_a + H_b \tag{11}$$

Both $H_á$ and $H_á$ meet Eq. 1. The solicitation is {φ} = ({φ_α}, {φ_β}), which is the direct sum of wave functions of Eq. 2 and spectral equations $E_á(Z)$ and $E_á(Z)$ are the same as Eq. 4. Green function is:

$$G_0(Z) = g_\alpha(Z) + g_\beta(Z) = \sum_{ij} g^{ij}\left(\left|i_\alpha >< j_\alpha\right| + \left|i_\beta >< j_\beta\right)\right. \tag{12}$$

Uni-coupling: Two knowledge chains have coupling relations at grid point i_0, (Fig. 3b) and the system is Eq. 11 plus the perturbation Hamiltonian:

$$H_1 = t_1(|i_{0\alpha}><i_{0\beta}| + |i_{0\beta}><i_{0\alpha}) \tag{13}$$

use Perturbation theory to get the Green function:

$$G_1 = G_0 + G_0 T_1 G_0 \tag{14}$$

$$T_1 = \sum_{n=0}^{\infty} (H_1 G_0)^n H_1 \tag{15}$$

and Scattering matrix is:

$$T_1 = \frac{t_1}{1-g_0^2 t_1^2}\left(\left|i_{0\alpha} >< i_{0\beta}\right| + \left|i_{0\beta} >< i_{0\alpha}\right.\right) + \frac{g_0 t_1^2}{1-g_0^2 t_1^2}\left(\left|i_{0\alpha} >< i_{0\alpha}\right| + \left|i_{0\beta} >< i_{0\beta}\right.\right) \tag{16}$$

then Green function is:

$$\begin{aligned} G_1 &= G_0 + \frac{t_1}{1-g_0^2 t_1^2}\sum_{ij} g^{ii_0} g^{i_0 j}\left(\left|i_\alpha >< j_\beta\right| + \left|i_\beta >< j_\alpha\right.\right) \\ &+ \frac{t_0 t_1^2}{1-g_0^2 t_1^2}\sum_{ij} g^{ii_0} g^{i_0 j}\left(\left|i_\alpha >< j_\beta\right| + \left|i_\beta >< j_\beta\right.\right) \end{aligned} \tag{17}$$

the matrix element is:

$$G_1(i_\alpha, j_\beta, Z) = \frac{t_1}{1-g_0^2 t_1^2} g^{ii_0} g^{i_0 j} \tag{18}$$

$$G_1(i_\alpha, j_\alpha, Z) = g^{ij} + \frac{g_0 t_1^2}{1-g_0^2 t_1^2} g^{ii_0} g^{i_0 j} \tag{19}$$

the probability of knowledge flow between two chains α and β can be calculated, the knowledge flow process from $i_á$ to $j_â$, is the process from grid point i in α to i_0 and then from i_0 in β to j, the probability of knowledge transfer is proportional to t_1.

Multi-coupling: Multi-coupling knowledge chain refers to there are many coupling relations among multiple grid points in knowledge chains α and β, its Hamiltonian is:

$$H = H_\alpha + H_\beta + \sum_i t_0\left(\left|i_\alpha >< i_\beta\right| + \left|i_\beta >< i_\alpha\right|\right) \tag{20}$$

based on the solicitation $H_0=H_á+H_â$ of coupling-free knowledge chain and expand the wave function of the system, so:

$$|\varphi_n| = \sum_k \left(u_{nk}\left|k_\alpha\right| + v_{nk}\left|k_\beta\right|\right) \tag{21}$$

here, $|k_\alpha|$ is Eq. 2, equivalent to $|\varphi_\alpha k|$, the matrix element is:

$$(k_a|H|k'_a) = E(k)\boldsymbol{\delta}_{kk'}, (k_\alpha|H|k'_\beta) = t_0\boldsymbol{\delta}_{kk} \tag{22}$$

E(k) is Eq. 4, thus isolated wave function of different k is unable to have transition in this coupling model. But if use the Hamiltonian matrix by the order $k_\alpha = k_1$, $k_\beta = k_1$, $k_\alpha = k_2$, $k_\beta = k_2$,..., it shows block diagonal form, wherein any piece is the same and the sub-block i is:

$$\begin{bmatrix} (\varphi_\alpha(k_1)|H|\varphi_\alpha(k_1)) & (\varphi_\alpha(k_1)|H|\varphi_\beta(k_1)) \\ (\varphi_\beta(k_1)|H|\varphi_\alpha(k_1)) & (\varphi_\beta(k_1)|H|\varphi_\beta(k_1)) \end{bmatrix} \tag{23}$$

the knowledge stock (energy) eigenvalue is:

$$\boldsymbol{\varepsilon}_\mp(k) = E(k) \pm t_0 \tag{24}$$

the index n in Eq. 21 can be replaced by k, for k has two energy levels, so there are two wave functions:

$$\varphi_\pm(k) = \frac{1}{\sqrt{2}}\left(\left|\varphi_\alpha(k)\right| \pm \left|\varphi_\beta(k)\right|\right) \tag{25}$$

Green function is:

$$\begin{aligned} G(Z) &= \sum_k \left(\frac{|\varphi\_(k)\varphi\_(k)|}{Z-\varepsilon\_(k)} + \frac{|\varphi_+(k)\varphi_+(k)|}{Z-\varepsilon_+(k)}\right) \\ &= \frac{1}{2}\sum_{ij} g_\pm^{ij}(|i_\alpha >< j_\alpha| + |i_\beta >< i_\beta| + |i_\alpha >< j_\beta| + |i_\beta >< i_\alpha|) \\ &+ \frac{1}{2}\sum_{ij} g^{ij}(|i_\alpha >< j_\alpha| + |i_\beta >< i_\beta| + |i_\alpha >< j_\beta| + |i_\beta >< i_\alpha|) \end{aligned} \tag{26}$$

And $g_{\pm}^{ij}$ refers that ε in Eq. 9 and 10 can be replaced by $\varepsilon \pm t_0$, from the calculation on the density of grid point state, it is formed by superposition of two single knowledge chain states density which staggered $2t_0$.

RESULTS

It can be concluded that different types of knowledge chains in KN have different coupling forms. For the coupling-free knowledge chain, probability of knowledge flows from grid points on different chains are completely equal and the Hamiltonian of KN system equals to the linear summation of different knowledge chains Hamiltonians, Green function is shown as Eq. 12; For the uni-coupling knowledge chain, perturbation Hamiltonian affects the system Hamiltonian and the probability of knowledge transfer is proportional to t_1, Green function is shown as Eq. 17; For the multi-coupling knowledge chain, the wave function of the system is expanded, its Green function is shown as Eq. 26. Obviously, three types of coupling have different knowledge exchange modes, which symbolize the intensity of cooperation in KN.

DISCUSSION AND CONCLUSION

The use of knowledge networks can meet the need of existing intricate knowledge and solve the structural contradictions of knowledge distribution. The study finds out that the existing studies of KN formation focus on the motivation and the process. Researches on the formation mechanism of KN mainly discuss the interaction among knowledge vertexes and less are involved in the interaction mechanism of clusters (such as knowledge chains) and its impact on the complex system of KN either. Some scholars state that knowledge network is formed merely by bilateral collaboration of knowledge subjects (Cowan *et al*., 2007; Carayanni and Alexander, 1999), the study of Seufert *et al.* (1999) underlines the relationship between organizations, Nowak (2006) uses 'network reciprocity' of individuals to explain cooperation in KN, moreover, 'proximity' of vertexes is also one key element to KN formation (Broekel and Boschma, 2012; Owen-Smith and Powell, 2004; Boschma, 2005). It can be seen that these previously published studies are just concentrated on the individual level, ignoring the interaction mechanism of clusters and whose impact on the macro-knowledge network complexity. The article argues that the formation of KN results from the interchain coupling of knowledge chains, which takes a macro perspective.

Specifically, it analyses the formation mechanism of knowledge networks from the perspective of 'interchain coupling of knowledge chains', proposes a coupling framework for knowledge networks and analyzes the coupling subjects, relationships and types, moreover, the study finds out that the types of knowledge chains in KN can be divided into 'coupling-free knowledge chain', 'uni-coupling knowledge chain' and 'multi-coupling knowledge chain' and the mathematical deduction exactly shows that interchain coupling of knowledge chains is the essential reason of KN formation.

ACKNOWLEDGMENTS

This study is supported by the Sichuan University's Special Research Program for the Philosophy Social Science (SKX201004) and Innovation Team Project of Education Department of Sichuan Province 'Knowledge Chain Management' (13TD0040).

REFERENCES

Anderson, P., 1999. Perspective: Complexity theory and organization science. Org. Sci., 10: 216-232.

Becheikh, N., R. Landry and N. Amara, 2006. Lessons from innovation empirical studies in the manufacturing sector: A systematic review of the literature from 1993-2003. Technovation, 26: 644-664.

Boschma, R., 2005. Proximity and innovation: A critical assessment. Regional Stud., 239: 61-74.

Broekel, T. and R. Boschma, 2012. Knowledge networks in the Dutch aviation industry: The proximity paradox. J. Econ. Geograph., 12: 409-433.

Buchel, B. and S. Raub, 2002. Building knowledge-creating value networks. Eur. Manage. J., 20: 587-596.

Cappellin, R. and R. Wink, 2009. International Knowledge and Innovation Networks: Knowledge Creation and Innovation in Medium Technology Clusters. Edward Elgar, Cheltenham, UK., ISBN-13: 9781848449084, Pages: 288.

Carayanni, E.G. and J. Alexander, 1999. Winning by co-opeting in strategic government-university-industry R and D partnerships, The power of complies dynamic knowledge networks. J. Technol. Transfer, 24: 197-210.

Cowan, R., N. Jonard and J.B. Zimmermann, 2007. Bilateral collaboration and the emergence of innovation networks. Manage. Sci., 53: 1051-1067.

Guler, I., M.F. Guillen and J.M. Macpherson, 2002. Global competition, institutions and the diffusion of organizational practices: The international spread of ISO 9000 quality certificates. Admin. Sci. Q., 47: 207-232.

Jarvenpaa, S.K. and H. Tanriverdi, 2003. Leading virtual knowledge networks. Org. Dynamics, 31: 403-412.

Liu, X., T.T. Jiang and F.C. Ma, 2013. Collective dynamics in knowledge networks: Emerging trends analysis. J. Informetrics, 7: 425-438.

Newman, M.E.J., 2003. The structure and function of complex networks. Soc. Ind. Applied Math. Rev., 45: 167-256.

Nowak, M.A., 2006. Five rules for the evolution of cooperation. Science, 12: 1560-1563.

Owen-Smith, J. and W.W. Powell, 2004. Knowledge networks as channels and conduits: The effects of spillovers in the boston biotechnology community. Org. Sci., 15: 5-21.

Phelps, C., R. Heidl and A. Wadhwa, 2012. Knowledge, networks and knowledge networks: A review and research agenda. J. Manage., 38: 1115-1166.

Rothwell, R., 1992. Successful in industrial innovation: Critical success factors for the 1990s. R&D Manage., 22: 221-239.

Seufert, A., G. von Krogh and A. Bach, 1999. Towards knowledge networking. J. Knowl. Manage., 3: 180-190.

Sorenson, O., J.W. Rivkin and L. Fleming, 2006. Complexity, networks and knowledge flow. Res. Policy, 5: 994-1017.

Wang, H.Y., 1993. Model investigations of coupled parallel chains. Acta Phys. Sinica, 40: 1627-1634.