An approach of detecting structure emergence of regional complex network of entrepreneurs: simulation experiment of college student start-ups

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Abstract

The article explores structure emergence of regional complex network of entrepreneurs, by proposing an integrated detection framework of community structure and its evolution based on social capital theory and complex network approach. Simulation of network dynamics, detection of community structure and tracing of network structure changes are integrated to investigate structure emergence and its link with entrepreneurs' social capital. And the article gives an experimental case about the emergence of stable network structure among a group of college student start-ups. Simulation result using the framework proposed by the article fits with actual network evolution traced in tracing program. The framework is effective and useful in explaining structure emergence of regional complex network of entrepreneurs.

Keywords: network structure; network dynamics; clique percolation; community detection; social capital

1 Introduction

Complex network of dynamical elements, such as internet, transportation network and social network, serve as natural models for a variety of complex systems [1]. In recent decade, the approach of complex network offers many insights for many physical or social phenomenons. In business arena, Complex network also provide the infrastructure upon which modern economics and regional business system depend [2]. Regional business system, with example ranging from inter-firm network, interlock of board directors, supply chains network to social network of entrepreneurs, are explored in literatures of business and strategy research. The complex network of entrepreneurs is tightly connected with the development and functioning of regional business system. In occasions of many developing countries, regional business system is operating under supporting of the complex network of entrepreneurs.

The traditional wisdoms of sociological theory and modern management theory consider social capital as vital variable in emergence of regional business network [2]. Social capital represents an important social resource tightly connected with social structure or social position within which an actor is located [3]. Entrepreneur's social capital is important for the emergence of regional business network and its functioning [4]. In early stage of start-up, entrepreneurs, especial young college student entrepreneurs, have to cultivate social capital to get connection with existing business network. Access to regional complex network of entrepreneurs is crucial for to gaining beneficial network resources for these young entrepreneurs. The complex network of entrepreneurs is in dynamics, continuously reshaped by active social interactions of entrepreneurs with high level social capital. In most of case, community structure of regional complex network of entrepreneurs tends to keep stable after emergence. Network structure can emerge and evolve in various ways. In the article, community structure is addressed. Community structure is found to be a common characteristic in many studies of network, such as computer and information network, biological network and business network, along with small world property, heavy-tailed degree distribution and clustering [5]. More efforts should be made to shed light to links between entrepreneur's social capital and structure emergence of regional business network. The purpose of the article is to propose a new framework to tracing and detecting emergence of community structure of regional business network, and provide a new instrument for simulation and positive research. In doing so, the article particularly observed structure emergence within a group of college student entrepreneurs in an experimental case.

The remainder of this article is organized as follows. Section 2 defines structure emergence as a stable states in network dynamics. Section 3 proposed a network generating method, in which social capital is transferred into a crucial input. Section 4 introduces new method of detecting community structure in stale state. Section 5 describe an experimental case about network emergence.

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2 Structure emergences in network dynamics

Structure emergence is a new steady state in network dynamics, which the network system reaches following a serial of social exchange rules. In a stable state of network dynamics, its major community structure would be lasting before the state is devastated. In a community, there are a group of individuals that is interconnected with each others. This community, which is also called as full coupling network or clique in complex network theory, is important structural aspects of realities of all kinds of social network. To describe network dynamic, denote a time-varying triple as following:

$$W(t) = [N(t), E(t), f(t): R], \quad (1)$$

In which, $W(t)$ is a dynamic network varying with time, $N(t)$ and $E(t)$ are respectively a set of nodes and a set of edges, $f(t)$ is a mapping function that defines the network shape by mapping edge set to node pairs. $f(t)$ plays a role like relational matrix in social network analysis. And denote $t = 0$ is the initial state. Denote network dynamics by a multi-local rule of the regular geometric T as following:

$$W(t+1) = T\{W(t), S(t)\}, \quad (2)$$

Where the rule T would be applied to each step of network dynamics of $W(t)$. $T(t)$ would make $W(t)$ transition to $W(t+1)$ until it reaches the final state $W(t_f)$. And $S(t)$ is the external force due to entrepreneur's social capital on $W(t)$. Here, $W(t_f)$ is a stable state, in which a stable structure emerges. And the structure remains unchanged for all $t \geq t_f$.

Network structure can be detected in varying ways. Here, community structure is employed to detect stable stage of network structure. In general, community structure is captured by clique percolation. Cliques or clustering property is very common in social networks, and is regarded as an essential of social interactions. The functioning of regional business system is tightly connected with entrepreneurs' clique or community structure. In this stable state, numbers of overlapping communities or K-clique would keep unchanged before the stable status is devastated. K-clique and overlapping community are often used to describe network structure in complex network theory and social network theory. K-clique is a full coupling network which constructed by K nodes. For example, 3-clique represents an interconnected triangle in a network. In following network operations, the article tries to figure out the biggest full coupling sub-graphs to find k-clique community.

3 Social capital and network dynamics

Social capital is an important conception in modern sociological theory, and tightly connected with another important sociological instrument, social network. In general, an entrepreneur with higher social capital will have much more capability to develop more social ties and business connections. The article suggested a network generation approach, including three main stages. First, define a generating measure on a unit square, then transform this generating measure into a link probability measure through a serial of iterations. Finally, generating links between the nodes according to link probability measures.

The article split a^2 rectangles by identically dividing x and the y axis of the unit square into a intervals. And assign a specific probability p_{ij} to each rectangle, subjecting to constraints of $\sum p_{ij} = 1$ and $p_{ij} = p_{ji}$. And sequence nodes or companies according to the level of entrepreneur's social capital, so that nodes representing entrepreneurs with higher level of social capital would be assigned with higher probabilities. Then, the link probability measure is calculated in complete analogy with standard process of generating a multifractal. In details, the article multiplies each rectangle with the generating measure k times. There are a^2k rectangles, associated with a link probability$p_{ij}(k)$. And the link probability is given as:

$$p_{ij}(k) = \prod_{q=1}^{k} p_{i_q j_q}, \quad (3)$$

In which, i_q is given by following equation:

$$i_q = \left[(i-1)\prod_{r=1}^{q-1} \circ \bmod a^{k-r}/a^{k-q}\right] + 1 \quad (4)$$

Where $\left[(i-1)\prod_{r=1}^{q-1} \circ \bmod a^{k-r}/a^{k-q}\right]$ is integer part of $(i-1)\prod_{r=1}^{q-1} \circ \bmod a^{k-r}/a^{k-q}$, the another term $\prod_{r=1}^{q-1} \circ \bmod a^{k-r}$ represents subsequent calculation of the remainder after the division by a^{k-r}. For convention, let $k = 1$, the link probability is equivalent to the generating measure itself.

The design of network generator in this article could be extended to be more general by substituting standard multifractal as following. Define $0 \leq R(x,y) \leq 1$ as a kth tensorial product of a symmetric 2d function defined on the unit square. In general cases, if $R_1(x,y)$, $R_2(x,y)$,……$R_k(x,y)$ is a sequence of symmetric measureable functions on the unit square. Define $R_k(x)$, given as following equation, as the average linking probability for a node at position x:

$$R_k(x) = \int_0^1 R_k(x,y)dy \quad (5)$$

And the average link probability , γ_k, of the whole network can be given as following:

$$\gamma_k = \int_0^1 R_k(x)\, dx \quad (6)$$

Suppose the number of nodes N_K and its corresponding to $R_k(x,y)$ subjects to following rules:

$$N_k \cdot R_k(x,y) \to \langle d \rangle \quad (7)$$

Then the degree distribution of a node at position x is expressed as following equation:

$$\varphi(d,x) = \binom{N_K}{d} R_k(x)^d [1 - R_k(x)]^{N_k-d-1} \quad (8)$$

In the thermodynamic limit, the above equation can be approximated by

$$\varphi(d,x) = \frac{N_K R_k(x)^d}{d!} e^{-N_k R_k(x)} \quad (9)$$

By integrating $\varphi(d,x)$, the degree distribution of the whole network is calculated as following

$$\varphi(d) = \int_0^1 \frac{N_K R_k(x)^d}{d!} e^{-N_k R_k(x)} dx \quad (10)$$

So, the probability of selection a isolated node is

$$\varphi(d=0) = \int_0^1 e^{-N_k R_k(x)} dx \quad (11)$$

As supposed in the above, there is

$$R_k(x.y) \rightarrow \langle d \rangle / N_k. \quad (12)$$

So, there is

$$\varphi(d=0) \cong e^{-\langle d \rangle} \cong 1 \quad (13)$$

this is, the majority of nodes will be isolated along with network dynamics. the considering condition for avoiding this situation is

$$\int_0^1 e^{-N_k R_k(x)} dx < A \quad (14)$$

In which, A is a less 1 constant. Considering limited network scale of real business network, the shortcoming is negligible. Finally, distribute N nodes independently according their levels of social capital, and then generate a network by linking each pair with a probability of $p_{ij}(k)$ at the given coordinates. The complexity of network generated by this method is increasing exponentially as long as k is increased. This section offers a simulation method for generating suitable network whose characteristics meet with functions of social capital. This work would extend the potential usage of the framework proposed in this article.

4. IDENTIFICATION OF COMMUNITY STRUCTURE

As suggested in section 2, stable community structure is used to judge whether a network dynamics turn into a stable state. In such a stable state, community structure does not occur major structural changes, e.g. expansion, split and merger, in a period of time. In following, the article would focus on two relevant issues: how to identify community structure, and how the community structure transitions to another steady state by external force from a period of time.

4.1 COMMUNITY STRUCTURE DELECTATION IN STABLE BUSINESS NETWORK

Based on previous works about clique percolation, the article proposed an algorithm for clique percolation (illustrated in Fig.1). The purpose of the algorithm is to detect all S size cliques that contain the initial node. Iterative regression algorithm is employed to detect procedure in the network from large clique to small clique.

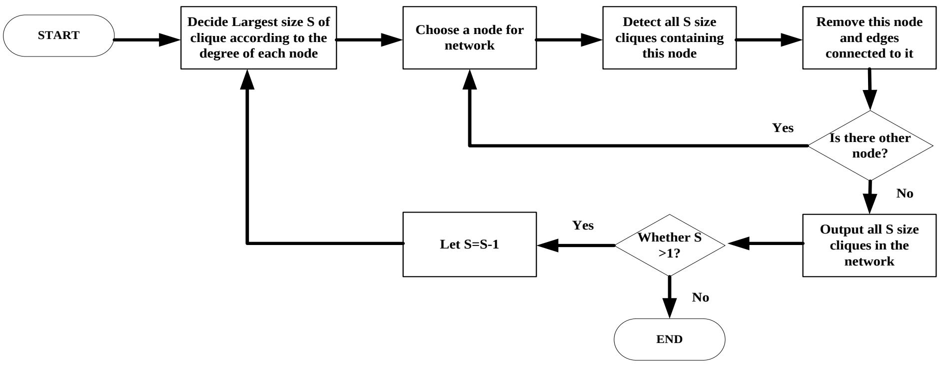

FIGURE 1 algorithm for clique percolation

Then the article proposed a community detection algorithm based on the clique percolation illustrated in Fig.1. All frictions can be found out by employing algorithm for clique percolation mentioned above, and transferred into cliques' overlap matrix. The diagonal elements of this overlap matrix represent the number of nodes in the corresponding clique, and non-diagonal elements is the number of overlapping nodes between two cliques. K-clique community structure connection matrix is obtained in following way. Deduct every diagonal element by k-1, every non-diagonal element by k, and denote resulting elements smaller than 0 to 0, other elements to 1. The above procedure is illustrated Fig.2.

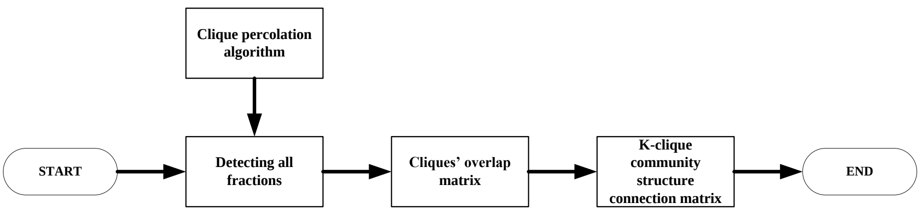

FIGURE 2 Detection procedure for community structure

4.2 TRACING COMMUNITY STRUCTURE CHANGE IN NETWORK DYNAMICS

Besides stable community structure of a regional business network, its changes of community structure varying with time are also meaningful. The above algorithm and procedure are useful in stable state, however these methods is not capable to tracing structural changes of communities in evolution process. Therefore, the article proposes a discriminant algorithm to trace community inheritance between the two generations in the process of network evolution. And the article designs a quantitative index to evaluate community stability during network dynamics.

Denote M_i and W_i as communities in two adjacent generations, then calculate superposition degree of all possible (M_i, W_i) pairs for every community as following:

$$C_{i,j}^{k} = |M_i^k \cap W_i^k| / |M_i^k \cup W_i^k| \quad (15)$$

Based on calculation of superposition degree, there are chances to discriminate stable stages in network dynamics. Then the article proposes a structural stability index for evaluating changes of community structure in network dynamics as following:

$$\rho = \sum_{T_X}^{T_Y-1} C(t, t+1) / (T_Y - T_X - 1) \quad (16)$$

In which, ρ is the structural stability index, i.e. the average ratio that the members of community remains within the time window (T_X, T_Y). For simplicity, a threshold value, ρ^*, is defined. For example, let's $\rho^* = 80\%$. Then the community structure is regarded as reaching steady state in time window (T_X, T_Y) if $\rho > \rho^*$. The details of this discriminant algorithm are illustrated in fig.3.

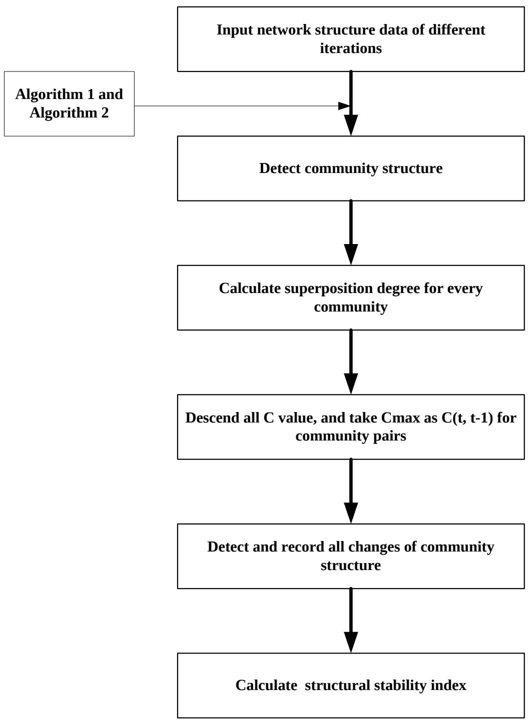

FIGURE 3 Procedure for detecting community structure stability

5 Simulation experiment about college s tudent start-ups

5.1 BACKGROUND

The structure of regional business network is important for regional economic development and entrepreneurship. And its structural changes are meaningful for an entrepreneur who wants to get sufficient resource to start up his own business. In this section, the article will use a concrete instance to experimentally exhibit structural emergence of regional business network taking fresh college entrepreneurs as experimental actors. In this way, the article would further explore the relationship between entrepreneurs' social capital and structure emergence of regional business network.

The article chooses to particularly observe social interactions among a group of college student entrepreneurs. College student entrepreneurs are active group in today's entrepreneurship. Access to regional business network and obtaining important social resource are particularly important issues for these young entrepreneurs. In many ways, the issue about structure emergence of social network among these young entrepreneurs is meaningful.

5.2 EXPERIMENT DESIGN

The article traced structure change of social network of 42 young college students who participated entrepreneurship training together in October, 2012 in Hangzhou, China. There are about 50 young entrepreneurs who was preparing for their start-ups participated the 2-week entrepreneurship training program. And 42 entrepreneurs effectively provide survey data about his/her social network at 5 time points, based on which network structures at 5 time point were constructed. Our tracing program was arranged as illustrated in fig. 4.

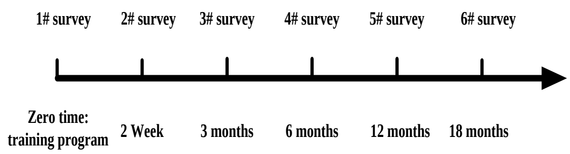

FIGURE 4 tracing survey arrangements

For convention, social interactions via famous social network software in China among these entrepreneurs are surveyed and abstracted to construct a simulated business network of these entrepreneurs. To be more specific, interaction history in Weibo, a kind of Chinese social network software, are surveyed in this tracing research. In 1# round survey, social capital of each entrepreneur is evaluated with 5-point likert scale according to their previous interaction level in Weibo software. And in each round of survey, these young entrepreneurs were asked to pick out these people who participated from the full list of participators in the training program. In this way, Actual social network of 42 entrepreneurs are constructed and compared with simulation network.

In the other way, the article designed a serial of simulation experiment using network generator, detecting method and tracing method for community structure. In initial stage, the dataset of social capital from 1# round survey is employed. As illustrated in the above framework, nodes with higher level of social capital would be manually assigned with higher linking probabilities. All simulations are conducted in the language of Matlab. Because the tracing program is limited to 18 months, and the rhythm of social interaction is quite slow than that of simulation experiment, the simulation step of network dynmics is limited to 40 rounds. Considering an entrepreneur would spend several months delicately to establish a important business relationship, this limitation is acceptable.

5.2 EXPERIMENT RESULTS

Fig.5 illustrated the actual change of community structure in the experimental case. The college student entrepreneurs were come from different classes and schools of Hangzhou Normal University. At the Zero time point, social interaction among these college student entrepreneurs is not intensive. When two week entrepreneurship training program was accomplished, the social interaction among this group of entrepreneurs reached highest level. After the program is finished, community structure is largely kept, as long as some communities experienced atrophy, expansion, split, merger, birth and demise.

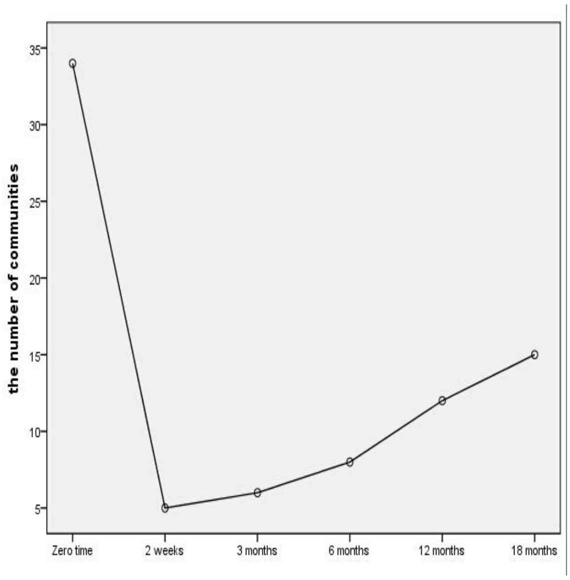

FIGURE 5 Change of community structure in actual case

The statistics of simulations (illustrated in Fig.6), in which the framework proposed by the article is used, shows a similar changing curve of community structure in the experimental case. The framework proposed by the article, to some extent, fit with actual changes in this case. The effectiveness of the framework seems promising.

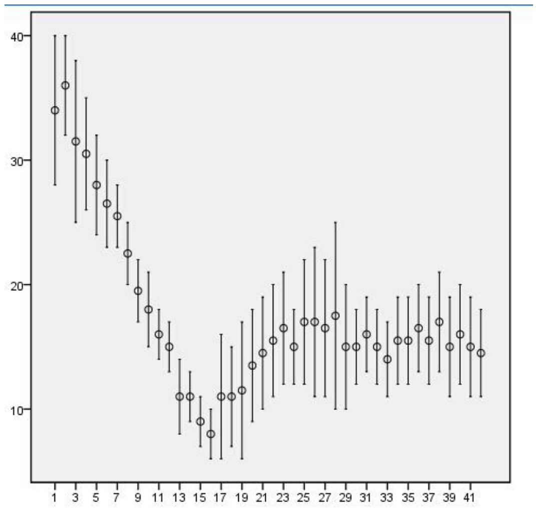

FIGURE 6 Simulation statistics about community structure

According to sociological theory, entrepreneur with higher level of social capital has more advantage in getting better position in regional business network. These position advantages includes more higher node degree and more structural holes. Fig.6 illustrated a rough correlation about entrepreneurs' social capital and the number cliques that he participated. Our research result show they are correlated ($R^2 = 0.645$).

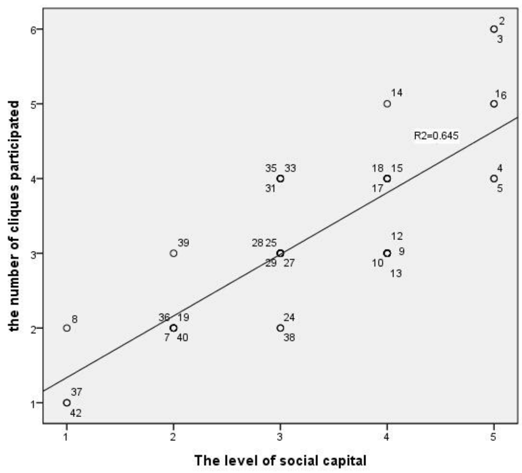

FIGURE 7 Corrltation between entrepreneurs' social capital and the number of cliques participated

6 Conclusions

In sociological theory and business management theory, regional inter-firm network is an important strategic resource for entrepreneurs and start-ups. Its structure is shaped by complex social interaction process, in which entrepreneurs' social capital play a subtle role. The article propose a framework to explore links between social capital and structural emergence of regional business network, which can be used in simulation research and positive analysis about real business network. And the article provides a concrete case about how a community structure is emerged from a group of young college student entrepreneurs. The article gives an experimental case about the emergence of stable network structure among a group of college student start-ups. Simulation results using the framework proposed by the article fit with actual network evolution. The experimental case showed the framework is effective and useful in explaining links between social capital and structure emergence.

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