The Voluntary Supply of R&D Investment for Generic Technology Based on Managers' Cognition of Brain

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ABSTRACT

Based on the enterprise managers' cognition of brain, the network game model of R&D investment for generic technology is proposed firstly, in which enterprise utility is consisted of ego utility and network utility. The ego utility comes from the impact of the generic and private technology on enterprise itself; The network utility of enterprise comes from the spilled utility of its adjacent enterprises along the enterprise social network which is determined by the altruism of the managers' brain cognition. Then, the best response function is constructed based on managers' altruistic cognition of brain by individual decision-makers, and the Nash equilibrium is also given; Some discussions are presented including the Pareto equilibrium for social decision-making, the impact of managers' brain cognition though social network on generic technology R&D investment. Finally, some simulations have been done for two types of networks and two different brain cognition weights on network game respectively. It is found that, regardless of the existence or absence of enterprise social networks, the voluntary supply of generic technology R&D investment is not enough due to the lack of altruistic brain cognition of managers, but the social network has a positive impact on voluntary supply. It is also found that the modular structure of "small world" in the network and the network shortcut can induce managers raising awareness of altruism and the voluntary contribution to the generic technology R&D investment. The conclusions have proposed a feasible path to increasing generic technology investment though raising mangers' brain cognition.

Key Words: Generic Technology, Altruism, Brain Cognition, Network Game, Voluntary Supply

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Introduction

To the organization or individual in the economic society, existing a certain degree of altruistic behavior is a well-balanced human mind and human behavior which is produced by natural selection and evolution, and it is an evolutionary stability strategy by human being. This makes the social structure free from the simple "scattered" society ecosystem, coming into the advanced "community" or "co-existence" society ecosystem (Johnson and Mislin, 2011). In the scene of specialization and cooperation, managers' altruistic behavior may form a behavioral strategy model which is advantageous to both oneself and community, which has been expounded in sociology, psychology, economic behavior and brain science.

Experts in economics and management use the theory of resource endowment complementarity to explain the voluntary nature of altruistic behavior. It is thought that altruistic intention is more urgent when the resource distribution is not enough institutionalized, and people need to exchange capability and resources to get greater benefit. And when to get the greater benefit, and when the competitiveness

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dominates the society, altruism will weaken (Fouragnan *et al.,* 2013). Therefore, altruistic decisions in economic behavior, such as voluntarily increasing the amount of generic technology research, will be the influence of social environment and the brain cognition degree of the managers.

Research based on brain science confirm the physiological support of altruistic behavior. It is considered that neurons are not only the evidence of long term evolution, but also the important mechanism of human behavior (Gambardella and McGahan, 2010). Studies of neuroscience suggest that humans perceive the feeling of others when they are performing altruistic acts, that is, such acts can accept both internal and external stimuli and then generate behavioral feedback to form effective interaction. Undoubtedly, these neuronal evidences point to empathy theory and PAM (Perspective Action Management) mechanism (Belfi *et al.,* 2015). Empathy as a perceptual and emotional response to other people's emotional experiences can be divided into cognitive empathy and emotional empathy. The intrinsic supporting mechanism of empathy is the PAM process by which the subject acts as awareness and then as feedback. Therefore, managers' degree of cognition to the altruistic behavior affects the social network in which the generic technology investment is confirmed.

Generic technology is the key foundation in an industry or cross-industries which can provide support for the progresses of other technologies, having broad application prospects and being the bodies of extending innovations. Many scholars have found that generic technologies possess some characteristics of quasi-public goods, such as investment insufficiencies. Compared with the social optimum, if they only depend on the voluntary contribution of enterprises managers who are lack of altruistic cognition, they will lead to serious market failures (Dou, 2015; Wang *et al.,* 2015; Wei *et al.,* 2015). In the premise of fixed total investment, network structure plays an important role in voluntary supply decision of industrial generic technology R & D investment because of its social capital and technology spillover. Therefore, this paper analyzes the impact of network structure which is shaped by managers' brain cognition on R & D investment of generic technology innovation by combining the social capital theory and the altruistic utility function of enterprise network.

The structure of this paper is as follows. In section 2, the network game and the utility function of altruism are reviewed. Section 3 constructs the network game model of generic technology R & D investment, and analyzes the utility function. Section 4 analyzes the Nash equilibrium and Pareto equilibrium of network game, and discusses the relationship between traditional public goods game and generic technology R & D investment. In section 5, the theoretical analysis is calculated and the experimental analysis is given. Finally, the conclusions of this paper are given.

Literature review

This paper focuses on the influences of social network structure which is shaped by managers' brain cognition and altruistic preference to voluntary supply of industry generic technology. Related theories involve two aspects: one is about voluntary provision of public goods, and the other is on altruistic utility function.

Voluntary provision of public goods

In the voluntary provision of public goods, Zhou *et al.,* (2013) analyzed the direct and indirect effects of heterogeneous types of individual social preferences and social roles on the voluntary supply of public goods. Their research showed that different social role cognitions directly affect the voluntary supply level of public goods. Bloch and Zenginobuz (2007) proposed a network game model of local public goods spillovers. In their model, participants divided their income into private goods consumption and public goods contributions, in which the utilities depend on the amount of private goods and public goods consumption. And participants were distributed in independent regions in which the numbers were already set and the spillover structure between regions was described by the adjacency matrix. Their study found that when the spillover intensity was relatively low (i.e., the sum of all rows in the adjacency matrix is less than 1), the equilibrium level of the public goods was unique while the increasing spillover intensity might lead to multiple equilibria. This study also found that the more the managers had cognition to altruism, the more the public goods were provided and the enterprises would benefit from others.

Bramoulle and Kranton (2007) have studied different public goods games based on network. In their model, the agent must make a decision on the expensive investment in the local public goods, and the return of the agent is a function of the sum of the contributions of the agent as well as its direct connected neighbors. There are two types of equilibria in this game: pure strategy and mixed strategy. They found that the former is socially optimal since some altruism agents invest in public goods while others not, and it connects the contributors and becomes the free rider of the neighbor's contributions. Interestingly, a new connection may reduce social welfare because it may reduce the altruism agent's contribution motivation. Sanditov *et al.,* (2016) found that managers' social networks play an active role in voluntary provision of public goods through the interdependent utility network game model.

In the aspect of co-evolution network and game, Lin and Wu (2007) studied the evolution strategy of the repeated prisoner's dilemma game by using genetic algorithm in complex networks. The results show that individuals with altruism memory in complex networks can evolve and form a self-organizing cooperation mechanism through gene duplication, recombination, mutation and selection. This cooperation mechanism not only can stimulate cooperative behaviors in the population, strengthen and maintain the cooperation behavior continuously, but also can punish and retaliate against individuals without altruism, thus making the complex network evolve and generate groups with high cooperation rate. Cao and Liu (2014) constructed a network evolution algorithm of industry-university-research-cooperation based on game theory by combining the topology structure of industry university research cooperation innovation network. Their research showed that the average node degree is U distribution and the number of nodes is L distribution; and that enterprises and research institutions with altruism awareness of choosing "positive and cooperative" strategy are the best scale of cooperation; and that the degree of preferential altruism mechanism is not conducive to the scale-free network node innovation diffusion; and that the combination of preferential attachment mechanism can maximize the promotion of small world network and random network in the diffusion of innovation.

Altruistic utility function

The study of altruistic preference in game has a long history, and a large number of research papers have already been produced. Here this paper mainly analyzes the related research results.

Becker pioneered the use of rational choice model for explaining altruistic preferences (Becker, 1976). His study considered that the altruism maximizes the sum of the adaptability of the giver and the beneficiary, and that the equilibrium of altruistic behavior is that the marginal adaptation of the giver is equal to the marginal adaptation of the beneficiary. Yang Chunxue (2001) also believed that the altruism of managers' cognition is not only about maximizing personal well-being, but also about the welfare of others.

Bergstrom (1999) focused on the individual systems of altruism and his study showed that under certain conditions, an interdependent system of utility function can be separated into an independent utility function system, which is defined as the individual preference of the possible distribution of personal consumption constraint sets. Rao Yulei *et al*., (2010) introduced the heterogeneous altruistic preference into the utility function of the game, and constructed a heterogeneous altruism model based on psychological utility to fit the centipede game experimental data. The results show that the altruistic preference is an important factor affecting the systematic deviation of the results of centipede game experiment and of Nash equilibrium predicted by traditional game theory.

Considered the altruistic preference, Xu Minli *et al.,* (2015) established an improved EWA learning model by using utility function instead of direct income, and carried out the calculation experiment analysis. His study found that a better learning effect is attained if the EWA learning model considers altruistic preferences. Social distance has a significant influence on the choice of strategy, so enterprises should pay attention to cultivating strategic partnership, reducing social distance and forming a long-term cooperative relationship.

In a sense, the social network is essentially a network of game participants' behaviors which affect their neighborhood gain, and the connection between them can be defined as the interdependence of utility. In the study of utility interdependence, social networks are used to explain the effects of a participant's earnings on their immediate neighbor's income. Bourles and

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Bramoull (2013) analyzed the transfer game on the network, which uses the utility function to define agent interdependence. They found that there was a unique internally balanced income portfolio for any social network and any utility function.

Based on the existing research results, it is found that the social network structure which is determined by managers' brain cognition has some influence on the voluntary supply level of the public goods, in which the utility spillover of altruism plays a key role.

Network game model and its utility analysis

Suppose that n enterprises in an industry cluster are faced with generic technology research and development. Based on the assumption of rationalization, each enterprise is willing to provide the funding and the amount is determined by managers' brain cognition. The total supply funding is equal to all companies' investment and the more the total supply, the higher the likelihood of success.

Based on the practical significance and research convenience, it may be assumed that: (1) each enterprise's sales revenue is only used for two types of technology research and development inputs: generic technology and private technology; (2) each enterprise has the freedom to determine the share of these two inputs in their sales revenue; (3) generic technology can directly benefit all enterprises in the cluster while private technology can only benefit itself directly, but the latter can overflow through social network and influence its neighboring enterprises; (4) the generic technology has the characteristics of quasi-public goods, so the addition of an enterprise benefiting from generic technology will not lead to increased costs. However, exclusion of an enterprise for sharing generic technology needs huge costs; this is to say, there are motivations for an enterprise to free ride (Dunning *et al.,* 2014).

Here this paper uses subscript $i \in (1, 2, ..., n)$ to represent n nodes in enterprise social networks. It assumes that the sales revenue of each enterprise is $w_i=1$ and that all sales revenue is used for two types of technology research and development investment. The proportion between the private and the industrial generic technology R & D investment is x_i and y_i, so, $x_i+y_i=w_i$.

This paper uses adjacency matrix A=$\{a_{ij}\}$ to denote enterprise social network, in which the element a_{ij} represents the relationship between enterprise i and enterprise j; this is to say, a_{ij} is the intensity of spillage from the utility of enterprise i to enterprise j. Making $a_{ii}=0$ shows that the utility of the enterprise has no self-feedback. Meanwhile, the spillover utilities are non-negative, so $a_{ij} \geq 0$. For a given enterprise, the utility of spillovers is only part of its utility, so $a_{ij} \leq 1$, in all, $0 \leq a_{ij} \leq 1$.

So, the utility of the node in the industry network consists of two parts: Ego utility and Network utility. The former is the utility coming from private and generic technology in the enterprise, while the latter is the overflow utility to enterprise i from other firms in social network.

Self-utility is a function of private technology R & D investment x_i and generic technology R & D aggregate supply Y, denoted by $u_i(x_i, Y)$, in which $Y = \sum_{i=1}^{n} y_i$. In this paper, Cobb-Douglas function is used as the self-utility function: $u_i(x_i, G) = x_i^{\alpha} Y^{\beta}$.

For firms, self-utility is proportional to R & D investment in private technology, so α=1. β is the elasticity coefficient of generic technology R & D investment for enterprise utility. Due to $\beta>0$, $\alpha+\beta>1$ represent that it is beneficial to enhance the innovation capability of industrial clusters by expanding the scale of investment in R & D of generic technology. Therefore, the enterprise's self-utility function is: 276

$$u_i(x_i, Y) = x_i Y^{\beta} \tag{1}$$

Network utility is the total utility of other enterprises in social networks, this is $\sum_{j \neq i} a_{ij} v_j$.

In summary, the total utility of nodes is:

$$v_i = u_i(x_i, Y) + \sum_{j \neq i} a_{ij} v_j \tag{2}$$

Making $V=(v_1, v_2, ..., v_n)$, $U=(u_1, u_2, ..., u_n)$ represents that the total utility vector and the self-utility vector of the node enterprise i respectively. Then the equation (2) can be written in the form of matrices: V=U+AV, therefore,

$$U=(I-A)V \tag{3}$$

Where I is the unit matrix.

By equation (2), if $\sum_{i=1}^{n} a_{ij} \geq 1$ indicates that the self-utility of the node enterprise is less than or equal to zero, it does not correspond with the actual situation, so $\sum_{i=1}^{n} a_{ij} < 1$. If there is any $i\in\{1, ..., n\}$, holding $\sum_{j=1}^{n} a_{ij} < 1$, then the matrix is diagonally dominant. Diagonally dominant matrices are reversible, and the elements of reversibility matrices are non-negative. Making $B=(I-A)^{-1}=\{b_{ij}\}$, then the equation (3) can be written:

$$V=BU \tag{4}$$

The elements of matrix B can be interpreted as a measure of the impact of an enterprise on another enterprise. Since $B = \sum_{t=0}^{\infty} A^t$ is the progression of powers of matrix A. The element *ij* in the matrix A^t represents the quantity of paths of the edge weighted product from enterprise *i* to enterprise *j*, whose length is *t*. Thus, b_{ij} is the sum of all the paths of proper weight, and these paths started from *i* and finished at *j* (Elliott and Golub, 2013). The sum of vectors of matrix B, namely, the Bonacich central vector, represents the impact of an enterprise on a social network.

In an enterprise social network, b_{ij} is used to show the utility overflowed from enterprise *i* to enterprise *j*, including direct spillover and indirect spillover (enterprise *i* spills over to its adjacent link and then spills over to the neighbor's neighbors, until to enterprise *j*), in which the intensity of the spillover is proportional to the intensity of the social relationship. The coefficient b_{ij} represents the total utility of all paths started from enterprise *i* and ended at enterprise *j*, so the overall utility of enterprise *i* on enterprise *j* utility can be tracked by social networks.

The diagonal elements b_{ii} of the matrix B corresponds to the returned utility of the enterprise *i*, in which due to the effect of private technology, the more enterprises' utility *i* increased, the more utility overflew to its neighbors and vice versa. In general, the more the paths from enterprise *i* to the end of enterprise *i*, the more b_{ii} depends on the size and density of enterprise expansion network. Therefore, b_{ii} is a measure of enterprise network embeddedness.

Equilibrium analysis of network game

Optimal response function

Equation (4) defines the preferences of enterprise node *i* for different assignments $x_{-i}=(x_1, x_2, ..., x_n)$. Given the selection vector x_{-i} of all other enterprise nodes, the enterprise node *i* maximizes its utility v_i by giving the constraint of total revenue equal to total expenditure, which means that the optimization problem is:

$$\max v_i(x_i, Y) = \sum_{j=1}^{n} b_{ij} u_j(x_j, Y) \tag{5}$$

s.t. $x_i+y_i=1$, $Y = n - \sum_{i=1}^{n} x_i$, $0\le x_i\le 1$

When $x_i\in(0,1)$, the first-order condition of the optimization problem is:

$$\frac{dV_i}{dx_i} = \frac{\partial V_i}{\partial x_i} + \frac{\partial V}{\partial Y}\frac{\partial Y}{\partial x_i} = \frac{\partial V_i}{\partial x_i} - \frac{\partial V_i}{\partial Y}$$

$$= b_{ii}\frac{\partial U_i(x_i, Y)}{\partial x_i} - \sum_{j=1}^{n} b_{ij}\frac{\partial U_j(x_i, Y)}{\partial Y}$$

$$= b_{ii}Y^{\beta} - \sum_{j=1}^{n} b_{ij}x_j\beta Y^{\beta-1} = 0$$

So,

$$b_{ii}Y = \beta\sum_{j=1}^{n} b_{ij}x_j \tag{6}$$

Because b_{ii} represents the sum of self-utility and network utility of private technology, the left side of the equation (6) indicates the marginal utility of private technology. Similarly, since b_{ij} describes the impact of the increase in the utility of enterprise *j* on the utility of enterprise *i*, the right side of the equation (6) collects all spillover utilities, which are the marginal utility of corporate generic technology investments. Therefore, equation (6) shows that the marginal utilities of private technology R & D investment are equal to the total of the network spillover utilities.

Because of $Y=W-(x_1+...+x_n)$, $W=n$ is the total contribution of enterprise nodes of generic technology research and development, so: $(1+\beta)x_i = n - \sum_{j\neq i}(1+\beta\frac{b_{ij}}{b_{ii}}x_j)$, so there are $x_i = \frac{1}{1+\beta}[n - \sum(1+\beta\frac{b_{ij}}{b_{ii}})]$.

In addition, the income condition constraints of the enterprise nodes determine two possible extreme points:

as $x_i=1$, the income of the enterprise node is all used for private technology R & D investment, here $b_{ii}Y > \beta\sum_{i=1}^{n} b_{ij}x_j$, that is, $n > \sum_{j\neq i}\left(1+\beta\frac{b_{ij}}{b_{ii}}x_j\right) + (1+\beta)$.

as $x_i=0$, the income of the enterprise node is all used for generic technology R & D investment, here $b_{ii}Y < \beta \sum_{i=1}^{n} b_{ij}x_j$, that is, $n < \sum_{j \neq i}\left(1 + \beta \frac{b_{ij}}{b_{ii}} x_j\right)$.

Finally, the optimum response function of enterprise nodes is

$$BR_i(x_{-i}) = \begin{cases} 0 & n < \sum_{j \neq i}(1+\beta \frac{b_{ij}}{b_{ii}} x_j) \\ 1 & n > \sum_{j \neq i}(1+\beta \frac{b_{ij}}{b_{ii}} x_j) + (1+\beta) \\ \frac{1}{1+\beta}[n - \sum_{j \neq i}(1+\beta \frac{b_{ij}}{b_{ii}}) x_j] & otherwise \end{cases} \quad (7)$$

As can be seen from the upper model, the optimal response function of the enterprise is a linear function of the actions of other firms.

Equilibrium analysis

Define variable z_i as $z_i = b_{ii} - \sum_{j=1}^{n} a_{ij} b_{jj}$ and vector **z** as $z=(z_1, z_2, ..., z_n)$, in which $b=(b_{11}, b_{22}, ..., b_{nn})$. Then vector **z** can be expressed in the form of a matrix as follows:

$$Z=(I-A)b \quad (8)$$

Define $\bar{z}$ as the average value of z_i based on i, $\bar{z} = \frac{1}{n}\sum_{i=1}^{n} z_i$. The following propositions give the existence conditions of internal equilibrium, and describe the equilibrium actions of corporate nodes that depend on their locations in the network.

Proposition 1: if for any $i \in \{1, ..., n\}$, there are $z_i \geq 0$ and $(z_i - \bar{z}) \leq \frac{\beta}{n}$, then there is a unique internal equilibrium vector $x^* = \{x_1^*, \dots, x_n^*\}$, in which $x_i^* = \frac{z_i}{\bar{z}+\beta/n}$ and for any $i \in \{1, ..., n\}$, there is $0 \leq x_i^* \leq 1$.

Proof: assuming that the budget constraint of the agent is not binding, the first-order condition (6) of the internal equilibrium can be written as: $b_{ii} = \sum_{j=1}^{n} \frac{\beta}{Y} x_j$, and expressed in matrix form as: $b = \frac{\beta}{Y} Bx$, in which vector x is $x=(x_1, x_2, ..., x_n)$.

According to $B=(I-A)^{-1}$, it can be got:

$$\frac{\beta}{Y}\mathbf{x} = (\mathbf{I} - \mathbf{A})\mathbf{b} \quad (9)$$

According to (8) and (9), it can be got

$$\frac{\beta}{Y}\mathbf{x} = \mathbf{z} \quad (10)$$

Therefore, $z_i = \frac{\beta}{Y} x_i$, then z_i is the marginal substitution rate of corporate i, $z=(z_1, z_2, ..., z_n)$ is the marginal substitute vector for all firms in the social network.

Supposing that the total amount of investment in private technology R & D by an enterprise is $x^* = x_1^* + x_2^* + \cdots + x_n^*$, by (10) it can be got that $X^* = \frac{Y^*}{\beta}\sum_{i=1}^{n} Z_i$. According to the constraint condition $Y=n-x$, here is $n - Y^* = \frac{Y^*}{\beta}\sum_{i=1}^{n} Z_i$. Therefore, the equilibrium level of R & D investment in generic technology is: $Y^* = \frac{1}{\bar{z}/\beta+1/n}$, then $x_i^* = \frac{Y^*}{\beta} z_i = \frac{z_i}{\bar{z}+\beta/n}$, $y_i^* = \frac{n\bar{z}+\beta-z_i}{n\bar{z}+\beta}$ would be got.

If for any $i \in \{1, ..., n\}$, there are $z_i \geq 0$ and $(z_i - \bar{z}) \leq \frac{\beta}{n}$, $0 \leq x_i^* \leq 1$, then x^* is the internal equilibrium of the network game. At the same time, since the linear equations b=Bz have the unique solution, the equilibrium is unique (certificated).

Discussion

In this section, the paper first analyzes whether the equilibrium of network game achieves the Pareto optimality, and then analyzes the impact of corporate social networks on R & D investment of generic technology.

Nash equilibrium and Pareto optimality

Above this paper has discussed that each enterprise can make its own decision independently by obtaining the equilibrium level y^* of the R & D investment of generic technology based on the objective function of maximizing the enterprise's individual utility function. Next, it is necessary to maximize the total utility function of all enterprises in an industrial cluster as the objective function, and to analyze the equilibrium level of R & D investment under the overall decision making.

Proposition 2: if for any $i \in (1, ..., n)$, there are $z_i \geq 0$ and $(z_i - \bar{z}) \leq \frac{\beta}{n}$, then there is a unique Pareto equilibrium vector $\hat{x}^* = \{\hat{x}_1^*, \dots, \hat{x}_n^*\}$, in which $\hat{x}_1^* = \frac{z_i}{\bar{z}+\beta}$, and for any $i \in (1, ..., n)$, there is $0 \leq \hat{x}_i^* \leq 1$.

Proof: according to equation (4), the optimal function of social welfare of enterprise groups is:

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$$V=\sum_{i=i}^{n}V_i=\sum_{i=1}^{n}(\sum_{j=1}^{n}b_{ij}U_j(v(Y),x_j))=\sum_{i=1}^{n}(\sum_{j=1}^{n}b_{ij}Y^{\beta}x_j)$$

Its optimization problem is: $\max V=\sum_{i=1}^{n}(\sum_{j=1}^{n}b_{ij}Y^{\beta}x_j)$.

s.t. $\sum_{i=1}^{n}x_i+Y=n$, $Y=\sum_{i=1}^{n}y_i$, $x_i+y_i=1$,
$0\le x_i\le 1$, $0\le y_i\le 1$

The derivative of the x_i is obtained:

$$\frac{dV}{dx_i}=\frac{dv_i}{x_i}+\sum_{j\neq i}\frac{\partial v_j}{\partial x_i}=b_{ii}Y^{\beta}-n\sum_{j=1}^{n}b_{ij}x_j\beta Y^{\beta-1}=0$$

so,

$$b_{ii}Y=n\beta\sum_{j=1}^{n}b_{ij}x \quad (11)$$

The upper equation indicates that the marginal utility of the private technology R & D investment is equal to the total of the network spillover utility.

By equation (11), it can be obtained: $b=\frac{n\beta}{Y}Bx$; by simultaneous equations (8):

$$\frac{n\beta}{Y}\mathbf{x}=\mathbf{z} \quad (12)$$

so, $z_i=\frac{n\beta}{x_i}Y$

Making $\hat{x}_i^*$ the optimal amount of private technology investment for the enterprise node i under the overall decision condition, that is, the Pareto optimum, $\hat{x}^*=\sum_{i=1}^{n}\hat{x}_i^*$. By equation (12), it can be obtained $\hat{X}^*=\frac{\hat{Y}^*}{n\beta}\sum_{i=1}^{n}Z_i$. According to constraint conditions $Y=n-\sum_{i=1}^{n}x_i$, there is $n-\hat{Y}^*=\frac{\hat{Y}^*}{n\beta}\sum_{i=1}^{n}Z_i$, so the Pareto optimal level of R & D investment is $\hat{Y}^*=\frac{1}{\bar{z}/n\beta+1/n}$, $\hat{x}_i^*=\frac{\hat{Y}^*}{n\beta}Z_i=\frac{Z_i}{\bar{z}+\beta}$ (certificated).

Comparing the two equilibrium states of industry generic technology R & D investment Y* and $\hat{Y}^*$, we can obtain: $Y^*=\frac{1}{\bar{z}/\beta+1/n}<\frac{1}{\bar{z}/n\beta+1/n}=\hat{Y}^*$. Therefore, the following propositions could be got:

Proposition 3: under the background of managers' social network, the equilibrium level of R & D investment cannot reach the social optimum level, which means that the voluntary supply of R & D investment of generic technology is insufficient.

The positive roles of social networks in generic technology R & D investment

The next step is to compare the network game model constructed with the standard model of voluntary supply of public goods. In the standard model, corporate social network was not taken into consideration, so there was no utility spillover effect. Therefore, it can serve as a useful benchmark.

In the traditional game model of voluntary supply of standard public goods, social relation based on managers' brain cognition between participants was not considered. It is usually supposed that the participants simply cluster together to form a group that does not have a network structure between participants. Since this is different from the actual situation, it is necessary to analyze the impact of social network on the investment in generic technology research and development.

Supposing that there is no social network in the industry cluster, that is A=0, so there is no spillover effect B=I. Similarly, the Lagrange multiplier method can be used to obtain the Pareto optimal solution: $\breve{Y}^*=\frac{1}{1/n\beta+1/n}$, $\breve{Y}_i^*=\frac{\beta}{1+\beta}$, $\breve{x}_i^*=\frac{\beta}{1+\beta}$.

With the maximization of the total utility function of the enterprise group as the objective function, the Lagrange multiplier method can also be used to obtain the Pareto optimal solution: $\breve{Y}^*=\frac{1}{1/n\beta+1/n}$, $\breve{Y}_i^*=\frac{\beta}{1+\beta}$, $\breve{x}_i^*=\frac{\beta}{1+\beta}$.

Due to $\tilde{Y}^*=\frac{1}{1/n+1/\beta}<\frac{1}{1/n\beta+1/n}=\breve{Y}^*$, it can be concluded that with the absence of corporate social networks, proposition 3 is equally true. This is the problem of the lack of voluntary supply of traditional public goods.

Since the existence or not of social networks can all induce the lack of voluntary investment in generic technology research and development, what is the role of social networks play in voluntary investment in generic technology research and development? Then the following propositions can be established.

Proposition 4: managers' social networks based on brain cognition encourage enterprises to invest in industrial generic technology research and development.

Proof: for social network matrices $A\neq 0$, due to that the mean of Z_i satisfies $\bar{z}=\frac{1}{n}\sum_{i=1}^{n}z_i<1$, so

$\mathrm{Y}^* = \frac{1}{\bar{z}/\beta+1/n} > \frac{1}{1/n+1/\beta} = \tilde{Y}^*$, $\hat{\mathrm{Y}}^* = \frac{1}{\bar{z}/n\beta+1/n} > \frac{1}{1/n\beta+1/n} = \breve{Y}^*$.

On the left of the upper two equations are the Nash equilibrium and Pareto optimality in the presence of social networks, and the right are the Nash equilibrium and Pareto optimality in the traditional sense without social networks. It can be found that under the condition of enterprise independent decision-making and overall decision making, the existence of social network makes the R & D investment of generic technology higher than that without social network. Therefore, managers' social networks based on brain cognition promote enterprises to invest in industrial generic technology research and development (certificated).

In this model, managers' social networks based on brain cognition allows an enterprise to internalize the positive externalities that arise from its generic technology investment. Therefore, the contribution of enterprises to R & D investment in generic technology is greater than that of a self-interested society.

To sum up, it can be said that managers' social networks based on brain cognition encourage enterprises to invest in generic technology, but the equilibrium level of voluntary investment in generic technology investment is lower than the social optimum level.

The experimental analysis of network game

Impact of enterprise social network location

Although for any agent, the "overall" positive impact of the social network on the public goods supply always dominates the "partial" negative impact, and the balance between the two depends on the position of the enterprise in the social network. The equilibrium vector *x** of private technology R & D inputs depends on the diagonal elements of the matrix B. The magnitude of the feedback spillover b_{ii} depends on the size of the enterprise's extended network (i.e., the number of neighbors, and of neighbors' neighbors etc.) and the connection density of the network. The greater and more intensive the expansion network is, the more spillover utility the network produces, and the greater b_{ii} can be obtained. The greater b_{ii} is, the more private investment in technology research and development can be achieved, and the contribution to public goods may be less.

To illustrate this, two categories of network described in Figures 1 and 2 are taken into account. In Figure 1 the network is constituted of three fully connected sub-network and a single node (type A), and the single node with a member of the cluster (type B) connected to each other in the network cluster (type D). In order to compare them, the network in Figure 2 consists of three different types of sub network and a single node (type A), and the single node is connected to each sub-network by a member of the cluster.

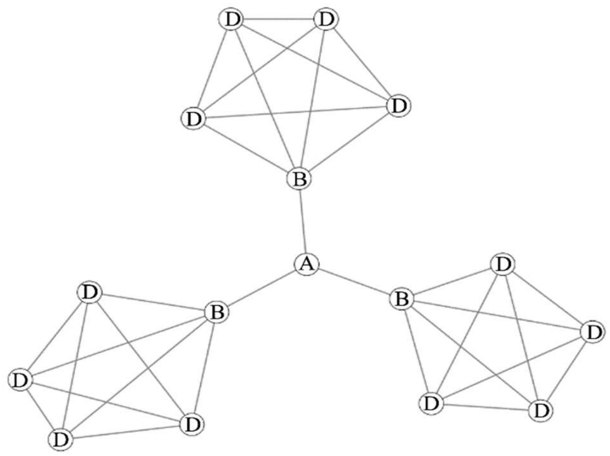

Figure 1. The network diagram of three types of nodes

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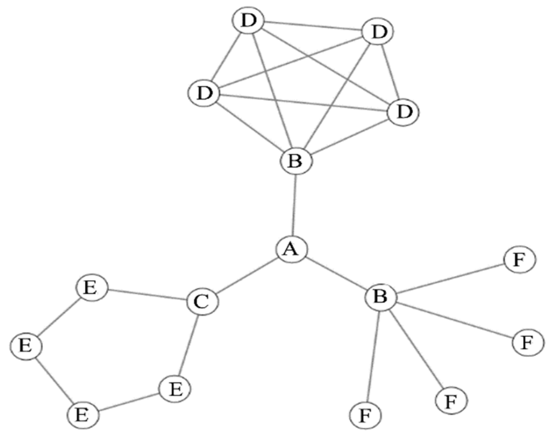

Figure 2. The network diagram of six types of nodes

For network 1, the greater the weight and embeddedness (b_{ii}) of the network, the more investment of generic technology research and development. Compared with the same weight network 1 and network 2, the voluntary supply of generic technology R & D of sparse network (network 2) is lower.

According to the types of broker roles in social network analysis, the central node enterprise (type A) is a "liaison broker" because it

Table 1. Node characteristics of two categories of innovation networks

Type	Network 1 (aij=0.2)				Network 1 (aij=0.02)				Network 2 (aij=0.2)				function
	number	zi	bii	yi	number	zi	bii	yi	number	zi	bii	yi	
A	1	0.167	1.250	0.505	1	0.941	1.0012	0.0289	1	0.9411	1.0012	0.0563	Integrated and decentralized
B	3	0.194	1.806	0.422	3	0.902	1.0021	0.0693	2	0.90195	1.0021	0.0955	Goalkeeper
C		-	-	-		-	-	-	1	0.96076	1.0008	0.0759	
D	12	0.319	1.701	0.051	12	0.922	1.0017	0.0491	4	0.92156	1.0017	0.0369	
E		-	-	-		-	-	-	4	0.96036	1.0004	0.0169	
F		-	-	-		-	-	-	4	0.96077	1.0008	0.0365	
	Y=2.3777				Y=0.82551				Y=0.8022				

bridges the blocked sub-networks. Type B and C of enterprise nodes are a "gatekeeper" because other members of the sub-network (type D) can be connected to the outside world through the "gatekeeper" structure hole. Type E of enterprise nodes has structural holes while type D and F of enterprise nodes do not, so they cannot play the role of broker in the network.

Type D of enterprise nodes is closely related within the sub-network, but is not directly related to the enterprises in other sub-networks. So, the investment in generic technology R & D investment is less attractive than its private technology R & D investment. As a result, companies with type D contribute less to industrial generic technology development than other individuals (Table 1).

For the broker who located at central network (type A), the ego network has the same size of the type D enterprise, but the network of type A is very sparse and there is no direct connection between the three neighbors. Although type A is outside any subgroup, its ego network spans all subgroups. In contrast to type D, it is more likely to invest in industry generic technology research and development because the spillover effects of all other firms cannot be neglected when the intensity of feedback spillovers is low.

Although the enterprises of type B and C belong to sub-networks, they still have an external connection (with node enterprise A) that links the "outside world" which prompt more investment to generic technology R & D. At the same time, as a part of a tightly connected cluster (Community), the enterprise node B also enjoys a high intensity of return overflow (higher b_{ii}). Therefore, in terms of industrial generic technology R & D investment, type B invests more in generic technology research and development than type C, but less than type A.

For overall inputs of industrial generic technology R & D (i.e. Pareto efficiency), the link between sub-networks (type A connectivity) is very important. There are two main reasons. First, as discussed above, such enterprises tend to contribute more to generic technology R & D than local firms with the same number of connections (type D). Second, by bridging other isolated sub-networks, enterprises of type A allow utilities to spill over to the cluster boundaries to produce a positive externality in their generic technology R & D investment and thereby encourage generic technology outputs.

The impact of network shortcuts

Many reality networks have a "small world" module structure: the network consists of a number of closely related communities and there are fewer connections between communities. In a densely connected community, there are multiple short paths between members and only a few short paths between communities.

The following analyses show the impact of network shortcuts on generic technology R & D investment. In this paper, a close-loop-network is shown in Figure 2, where an enterprise has k edges connected to each side of its adjacent enterprise, and all connections have the same weight a. Thus, the degree of the node in this close-loop-network is equal to $2k$ (the close-loop-network in figure 2 is $k=2$).

We add a new connection between two companies that are not directly connected (see the dotted line shown in Figure 3), which can be called network shortcuts. The network shortcuts shorten the distance between companies in different communities that are far apart from each other and become a kind of bridge link.

According to proposition 4, the greater the weight of network relations a, the stronger the impact of corporate social networks on generic technology research and development. Maintaining a network shortcut length of 6 constant (that is, adding a connection between node 1 and node 7), it can be founded that the generic technology R & D investment increments before and after shortcut increasingly change with the network relationship weight a, as shown in figure 3. As expected, Y is an increasing function of a.

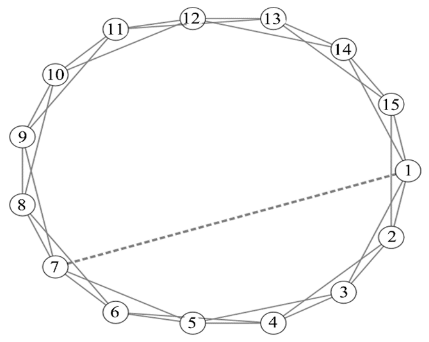

Figure 3. a close-loop-network with network shortcuts

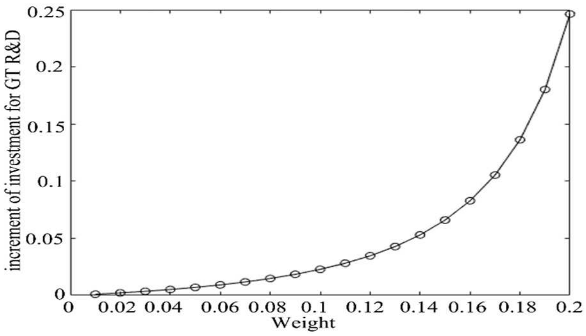

Figure 4. Relationship between increment of R & D input and network weight

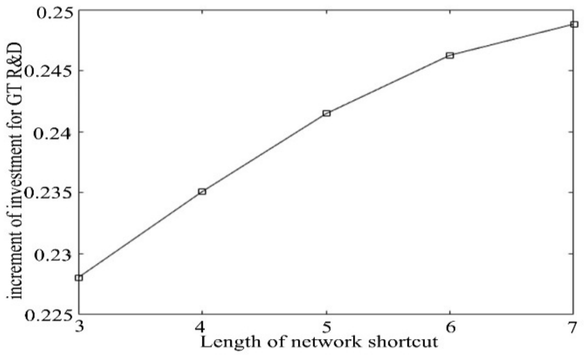

Figure 5. Relationship between incremental R & D investment and network shortcut length

In addition, this paper also analyzes the impact of network shortcuts on the incremental investment in generic technology research and development. For the close-loop-network, the network shortcut has a maximum span length of 7 and a minimum span length of 3. Maintaining the network weight constant (that is a=0.2), this paper finds that the increased shortcut span length range is 3~7. The generic technology R & D investment increments before and after shortcut increasingly changing with the length of the network shortcut relationship is shown in figure 5. Figure 5 shows the impact of network shortcuts across distance d on generic technology research and development. The curve in the graph shows that the longer the shortcut crosses, the more generic technology research and development investment will be.

Conclusions

In this paper, based on the cognition of managers' brain cognition, the network game model of the voluntary input of R & D investment is constructed, and the influence of network structure on game equilibrium is analyzed.

The network game model of this paper has the following characteristics. Firstly, the utility of an enterprise can spill over through the social network to other enterprises associated with it. Therefore, the motivation of enterprise managers to invest in R & D of generic technology is not only directly increasing their effectiveness, but also prompting the welfare of its adjacent enterprises. It is altruistic motives that is determined by managers' brain cognition. Secondly, the generic technology in the model is global, and can benefit every enterprise in the world. The social network here is based on managers' brain cognition and is essentially an interactive network of utility. Thirdly, private technology is actually a kind of "local public goods", which is complementary to generic technology because of the spillover of the earnings.

Like other network games, the author is interested in the result of equilibrium, and the relationship between network structure based on managers' brain cognition and the equilibrium level of public goods.

One conclusion of this paper is that mutually beneficial social networks can help alleviate the classic problem of insufficient voluntary supply of public goods. However, the classical model is too simple and fails to take into account the complex dynamic relationship between corporate behavior and managers' brain cognition. In fact, the two types of social capital are complementary and interdependent in the overall level of industrial clusters and at the individual level of enterprises. For example, through mutual voluntary cooperation and managers' brain cognition, enterprises can establish a wide range of trust in the industrial cluster, and in turn, trust can promote mutual cooperation among enterprises. Therefore, the establishment of altruistic brain cognition by managers can contribute to this positive circular mechanism.

In innovation networks, it is generally believed that R & D collaboration between organizations is an important mechanism for the diffusion of modern knowledge of science and technology. This belief is largely strengthened by brain cognition of managers. Under the circumstance of managers' brain cognition, Model results show that R & D networks not only can serve as a knowledge diffusion mechanism, but also can create additional incentive schemes that contribute to generic technology and private technology research and development.

Another conclusion of this paper is that, based on the theory of managers' brain cognition, a new organizational psychological mechanism has been developed among enterprises. Some organizations can exclude "simple and direct" rational calculation of selfishness and altruism, and develop the altruistic behavior of the non-stakeholder. This behavioral strategy can also have irrational emotional characteristics. This kind of social emotion is a very stable behavior strategy, which is beneficial to the stable cooperation of social economy. Hence, based on the theory of managers' brain cognition, companies have more incentives to invest in generic technology because industrial networks can help them internalize larger parts of positive externalities. Thus, in densely connected clusters (such as companies in the same area), encouraging cooperative policies may stimulate firms to invest with the knowledge that the local type will benefit themselves and their immediate connected firms. In addition, in order to encourage the production of such "global" generic technology knowledge, policy makers can make full use of the manager's altruistic cognition to establish shortcut links in the existing sparse-connected research and development network.

Acknowledgements

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