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Clique Structure and Enterprise Innovation: An Empirical Research on China's High-End Equipment Manufacturing Industry

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Abstract

Clique problem has been fully researched in the social relations network of sociology，But the cliques in inter-enterprise networks have attracted people's attention in recent years. Based on the alliance data of the high-end equipment manufacturing industry in China in 2000-2013, we construct innovation network，and use negative binomial regression models to analyze the impact of the clique structure on enterprise innovation. The results show that the more the clique numbers in the alliance innovation network, the stronger the enterprise innovation capability. Whether the enterprises listed have a negative moderating effect on the impact of clique numbers on enterprise innovation performance. That is, for the listed enterprises, more clique numbers cannot significantly promote enterprise innovation, but for non-listed enterprises, more clique numbers are conducive to enterprise innovation. Innovation accumulation has no significant positive moderating effect on the impact of clique numbers on enterprise innovation performance. The impact of the coreness values on the enterprise innovative output in an inverted-U curvilinear way, and the coreness values also moderates the effect of innovation accumulation on enterprise innovation capability in an inverted-U curvilinear way. The conclusions of the research can provide the basis for the enterprise to embed the network cliques and for the relevant government departments to formulate the alliance policy.

Keywords: innovation network, cliques, high-end equipment manufacturing industry

1. Introduction

Innovation has become an important way for enterprises to obtain the advantage of development. However, with the promotion of market internationalization, the relevant products and technology of Chinese enterprises are strongly affected by the international market. The complexity of product and technological innovation makes more enterprises realize that their resources cannot meet the needs of international competition. Based on the complement of knowledge resources and innovation ability, enterprises choose to cooperate with each other, the link between enterprises is getting closer and closer, the boundary is becoming more and more vague, and the innovation behavior of individual enterprises is gradually turning into group innovation behavior.

The strategic alliance based on cooperative innovation is an important way for enterprises to acquire innovative resources, which can not only avoid innovation risk, but also play a key role in improving the innovation ability of enterprises. The formation and development of alliance innovation network has become the main way of enterprise innovation (Zheng Zhun, Yu Yajun, Wang Guoshun, 2012). However, this kind of network has a significant structure of core-edge (Rank, C., O. Rank, et al, 2006). Among them, the group based on the mutual choice between the network members of the reciprocal relationship is called the cliques, which is a local network gathering phenomenon in the process of innovation network evolution. At present, more scholars have discussed the cliques' problems in the network of interpersonal relationships, but the issue of the cliques in the enterprise network has attracted people's attention in recent years.

In the study of interpersonal relationships, some scholars believe that the cliques structure has the boundary limits ability to the network members to obtain information and resources to a certain extent (Singh, J., M. T. Hansen, et al, 2010). In relation to the network of interpersonal relationships, middle-level cliques can lead to many more performance (Fang, C., J. Lee, et al, 2010), The formation of cliques in the network of interpersonal relationships improves the satisfaction of people in the cliques, but reduces the satisfaction of the Outsiders.(Wang Haizhen, Liu Xinmei, Zhang Yongsheng, 2011). Only a few scholars have explored the cliques of the inter-enterprise network. For example, Chinese scholars have explored the phenomenon of “quanzi” in social relations network in China, and based on the idea, they analyzed the social network structure and complex adaptation of enterprises (Luo Jiade, Zhang Tian, Ren Bing, 2014). At the same time, some scholars have also explored the phenomenon of “baotuan” in China’s automobile enterprise alliance, and that this kind of “baotuan” is conducive to the innovation of the enterprise, on this basis, the impact of coupling between cliques and knowledge flow in alliance network on enterprise innovation capability is discussed (Zhao Yan, Meng Qingshi, 2014; Zhao Yan, Feng Weiyu, Zheng Xiangjie, 2016). But from the current research, the research about the cliques in the enterprise innovation network is still in the exploration stage, although some scholars have tried to study the cliques of inter-enterprise networks, however, in the face of the choice of cliques, how to embed, and how much embedded in order to be more conducive to innovation has become a difficult problem for the enterprise choice.

In view of this, our research is based on social network theory, and put forward research hypothesis. We choose 2000-2013 years of China's high-end equipment manufacturing enterprises to build innovation networks, not only do we consider the impact of cliques number on enterprise innovation in the whole network, but also analyze the impact of the coreness values on the innovation capability in the individual network. On the basis, we explore the moderating effects of whether the enterprise is listed as well as their own innovation accumulation. Based on these conclusions, we put forward some policy suggestions for the enterprise to embed the network cliques and for the relevant government departments to formulate the alliance policy.

2. Theoretical Hypothesis

2.1 Clique and Enterprise Innovation

The clique refers to “the maximum complete subgroup containing at least three nodes”（Wasserman S, Faust K, 1994）, the formation of cliques within the network provides a structural basis for the effective flow of knowledge within the network, on the basis of enhancing mutual trust among enterprises(Zhao Yan, Meng Qingshi,2014; Zhao Yan, Feng Weiyu, Zheng Xiangjie,2016). On the one hand, the relationship between enterprises within cliques is more frequent than that of other enterprises based on reciprocal relations, which not only improves the sped of knowledge flow, but also obtains more valuable resources for innovation by comparing diversified information; on the other hand, the reciprocal relationship between enterprises in multi-level cliques, deepen mutual understanding and trust and promote deeper cooperation, such as the frequent interaction and communication between enterprises will induce the transfer of tacit knowledge that plays an important role in innovation. Therefore, the more the clique organizations in the innovation network, the more conducive to the diffusion of knowledge and information, and the enterprises embedded in cliques can get more abundant innovative resources from clique organizations.

Innovation is not only an inexhaustible driving force for sustainable development of enterprises, but also an important way to obtain competitive advantages, increasing high-tech enterprises invest more capital in enterprise innovation. Te high and new technology listed companies with strong capital are often able to obtain more innovative resources through the market approach, as for the unlisted high-tech enterprises, due to the limitation of their capital size; they tend to seek more resources to enhance their innovation ability.

The impact of the resource location of the enterprise on the network has been confirmed, and they early innovation accumulation can promote the follow-up innovation output of the enterprises (Zhao Yan, Liu Zhongshi, 2012). However, it’s often difficult for enterprises with less innovation and accumulation to interact and communicate more knowledge sharing with other enterprises in the cliques, on the contrary, more innovation accumulation can provide innate guarantee for the knowledge sharing among the enterprises in the cliques. Therefore, the more innovation that the enterprise has, the more the cliques group can promote the innovation of the enterprise. So we put forward the hypothesis:

Hypothesis 1: The more the number of cliques in the alliance innovation network, the stronger the innovation ability of embedded enterprises.

Hypothesis 2: whether the enterprise is listed or not has a negative adjustment effect on the influence of the number of clique groups on the innovation performance.

Hypothesis 3: The accumulation of enterprise innovation has a positive effect on the influence of the number of clique groups on the innovation performance.

2.2 Coreness Values, Innovation Accumulation and Enterprise Innovation

In social network analysis, if all the points of a subgroup are at least adjacent to the K other points in the subgroup, the subgroup is called K-core. Coreness values, CV refers to the k-core in the condensed subgroup in which the node is located. Enterprises are embedded in the alliance innovation network, and they are also choosing different aggregation subgroups. When enterprises are embedded in the cohesive subgroup of K-core, the number of directly connected relationships increases with the increase of K value, and the degree of embeddedness of enterprises is also enhanced, because each enterprise in the condensed subgroup is connected with at least k other enterprises, this will benefit the circulation of information resources among the enterprises within the subgroup, and increase the opportunities for the acquisition of external heterogeneous resources by the embedded enterprises. However, with the K value increased to a certain extent, more inter enterprise connections may increase the probability of obtaining redundant information from the enterprise, making the knowledge resources obtained from multiple paths become consistent and redundant, it’s hard to grab valuable innovation resources even costs a lot of embedded costs (Zhao Yan, Zheng Xiangjie,2013). With the further increase of the number of inter firm relationships, the core technology of embedded enterprises is gaining the alliance partners while worrying about their competitive. Meanwhile, it also increase the opportunity of knowledge sharing by partners, this will not only increase the number of competitors, but also improve the competitive strength of the competitors. At this point, embedded enterprises will consciously protect their core knowledge and technology, reduce knowledge sharing and communication(Zheng Xiangjie, Zhao Yan,2013), and further affect embedded enterprises’ effective access to higher value knowledge resources, which is not conductive to enterprise innovation.

In addition, when the core degree of the embedded enterprise is low, the enterprise’s own innovation accumulation can promote the enterprise innovation(Zhao Yan, Liu Zhongshi,2012), but at this time, the number of enterprises in the group is less, the innovation resources from outside are limited and the level of innovation output is relatively low. With the increase of enterprise core degree, more inter enterprise relationship provide more opportunities for enterprises to obtain external innovation resources. However, when the core degree is higher and exceeds a certain value, on the one hand, it causes enterprises to obtain more redundant resources, and the unified standards and standards set by enterprises within the group will also limit the innovation of enterprises to a certain extent; on the other hand, there are more network relationships among groups that cause companies to worry that some of the “temporary cooperation” competitors can easily get their own core technical resources (Zheng Xiangjie,2013), those who do not want to have too much communication and affect the implicit knowledge of the important role of enterprise innovation will also limit the innovation of enterprises. Thus, we put forward the hypothesis:

Hypothesis 4: there is an inverted U relationship between the core degree of the embedded enterprise and its innovation capability.

Hypothesis 5: the core degree of embedded enterprises has an inverted U regulation effect on the innovation ability of enterprise innovation accumulation.

3. Data, Variables and Models

3.1 Data

The data used in this study to build an alliance innovation network is based on the SDC platinum database in the United States; a database of China’s high-end equipment manufacturing industry alliance is built in accordance with the division standard of the high-end manufacturing industry in China’s strategic emerging industries. But for the enterprise patent data（1995-2015）, it is mainly acquired through China Intellectual Property Net (http://www.cnipr.com).

Since the end time of inter-firm alliance is rarely release, international research practices assume that the duration of each alliance is 3 to 5 years, so our study base on 4-year windows, through designing an undirected two element adjacency matrix algorithm to obtain the adjacency matrix of the alliance network automatically, and form 11 time windows of alliance innovation network (2000-2003, 2001-2004,…… 2010-2013), then we calculate the relevant structural index and construct the model.

3.2 Variables Specification

3.2.1 Dependent Variable: Patent Number

High-end equipment manufacturing enterprises belong to high-tech enterprises, and they tend to apply for patents to protect their own innovations. Therefore, the enterprise's patent number can reflect their innovation ability to a certain extent. In this study, the number of patents applied and approved by the enterprise was used as the dependent variable.

3.2.2 Independent Variables

1. Cliques Number, CN

The Clique is "the largest complete subgraph" of which the enterprises in it are connected to other enterprises, and the clique cannot be included by any other cliques. Therefore, the number of cliques in the alliance's innovation network can reflect the degree of "aggregation" of the enterprise in the whole network, and there is a trend of "three element closure" between enterprises associated with structural holes in the network. This trend has also become an important embodiment of the "form cliques" between enterprises in the alliance innovation network (Zhao Yan, Meng Qingshi, 2014). Therefore, this study uses the clique numbers in the alliance innovation network of each window as the independent variable into the model, based on the calculation method of social network analysis (Luce R and Perry A,1949; Bron C and Kerbosch J, 1973), use UCINET software to obtain and analyze the value of the index.

2. Coreness Values, CV

Besides the cliques, the *K*-coreness values based on the degree is also an important index reflecting the subgroup in the network. It is obtained by restricting the number of adjacent of each member in the subgroup (Seidman S, 1983). In different *K*-coreness, enterprises have different core degrees, and the complexity of dealing with and maintaining the relationship between enterprise is not the same for obtaining innovation resources. The core degree of the enterprise is based on the individual of the enterprise, which embodies the degree of "pile up" among the enterprises within the condensed subgroup of the enterprise. Based on the calculation method of social network analysis(Seidman S, 1983), using UCINET software to obtain and analyze the value of the index.

3. Presample 5

The original innovation results of the enterprise have laid a solid foundation for future enterprise innovation, therefore, the enterprise innovation ability with more innovation results is stronger (Blundell, R. R., R. Griffith, J. Van Renee, 1995; Schilling, M. A., Phelps, C. C, 2007). We use the sum of enterprise's innovation for 5 years before embedding the alliance innovation network to represent the enterprise innovation accumulation as the control variable into the model.

4. Public

The listing of enterprises provides an important way to raise innovative funds from the capital market, and the listed companies will have more innovation opportunities than the general enterprises (Zhao Yan, Zheng Xiangjie, 2013). In this study, whether or not the enterprise is listed as a control variable into the model, if the sample enterprise is listed, then *public*=1, or *public*=0.

3.2.3 Control Variables

Many studies have shown that network structure indicators such as *Clustering coefficient, CC, Betweenness centrality, BC, and Network density, ND* etc., will affect the innovation capability of embedded enterprises. Therefore, we take the *Clustering coefficient, Betweenness centrality, and Network density* as the control variables to enter into the model.

3.3 Model Specification

We know that use the count data as the interpreted variable enters into the model, the linear regression model may lead to ineffective and biased estimates, while the patent data are non-negative counting date, then Poisson model can be considered. But the expectation of the explanatory variable is equal or approximate to the expectation of the Poisson regression, and the variance of the variable patent number is obviously greater than the mean vale in this study (It is available by table 1), there exists "excessive dispersion", considering the use of the "negative two regression" model, that is, the samples are derived from negative two distribution and are estimated by maximum likelihood estimation.

Enterprise embed in the alliance innovation network, from the establishment, cooperation and development to the application of innovative achievements in the form of patent and approval, often takes 2 years or even longer, in order to study the robustness of the results, this study considered the cliques number of alliance, enterprise core degree and the influence of related variable on the innovation performance of 2 years lag to build the models such as table 2.

4. Results and Discussion

Table 1 is the descriptive statistics and correlation analysis of variables. It can be seen that the variance of the number of patents (Square of standard deviation) is obviously greater than the mean, which indicates that the

Poisson model is not appropriate. The absolute values of the correlation coefficients between the respective variables are less than 0.7, so there is no multicollinearity problem among the variables.

Table 2 is the result of negative binomial regression analysis of random effects. The results of Hausman test show that the negative binomial regression model using random effects is more effective. Through the test of goodness of fit, when the dispersion parameter is zero, the negative binomial regression is Poisson's regression. For each model, likelihood test can get the original hypothesis that P value is small, so that to reject the original hypothesis that data obeys the Poisson distribution, that is to say that negative binomial regression is more appropriate.

From model 1, it can be seen that the innovation accumulation of the enterprise itself has a significant positive impact on its innovation performance after its embedding of the alliance innovation network. This shows that the enterprise must innovate, "it takes a good blacksmith to make good steel", actively increasing the accumulation of innovation and improving the ability to acquire and absorb external innovation resources to promote innovation better. The listed enterprises have more innovative capital, can exchange more innovative resources through capital and the enterprise's innovative ability is strong. However, the impact of agglomeration coefficient on enterprise innovation is not significant, which is different from that of scholar's research on the innovation network of American high-tech enterprise alliance(Schilling, M. A., Phelps, C. C,2007), and supports the research conclusions of the Chinese high-teach enterprise alliance innovation network(Zhao Yan, Zheng Xiangjie,2013). The center degree of intermediary has no significant influence on the innovation performance of the enterprise, which shows that the enterprises who occupy the superior network position have not played a position advantage. The network density has a significant negative impact on enterprise innovation, which indicated that more network relationships in the whole network can not only promote the innovation of embedded enterprises, but also hinder the development of enterprise.

In the model 2, the clique number has a significant positive impact on embedded business innovation performance. Therefore, assuming that 1 is supported, that is, the more the number of cliques in the alliance innovation network, the stronger the innovation ability of the embedded enterprise. The product terms of public and CN are added in the model 3, in order to eliminate the influence of multiple collinearity, the coefficient of product item is significantly negative after public and CN are processed centralization, indicating that there is a significant negative regulation effect. The hypothesis 2 is also verified. Similarly, in model 4, we increase the product term of Presample5 and CN after centralization, but the coefficient of product terms are not significant, indicating that there is no significant moderating effect, assuming that 3 has not been verified.

Through model 5, we can get that the first degree coefficient of core degree is positive, while the two order coefficient is significantly negative. This indicates that the influence of core degree on enterprise innovation performance presents an inverted U relationship, so the hypothesis 4 is supported. In order to ensure the robustness of conclusion, after centralization of the natural logarithm of Presample5, the results of the first and two cubic centralization of the core are multiplied into the model 6 respectively, the results show that the core two degree multiplied by the coefficient of innovation accumulation is significantly negative, indicating that there is a moderating effect, at the same time, the factor of the core degree once multiplied by the innovation accumulation is positive, indicating that the core degree affects the innovation accumulation of enterprise innovation output with the regulation effect of inverted U.

In order to further analyze the moderating effect of the listing coefficient on the innovation performance of embedded enterprises, the two negative regression analysis is conducted at public=0 and public=1 respectively. As in Table 3, when public=0, the coefficient is positive, and when public=1, the coefficient of the clique number is not significant. Suppose 2 is further supported.

Based on the analysis results of model 6, we draw the regulatory effect diagram of core degree in order to clearly illustrate the moderating effect of core degree on the impact of innovation accumulation on enterprise innovation performance, as is shown in Figure 1. The innovation accumulation has a significant positive impact on the innovation of the enterprise itself, but this effect is regulated by the core U type. With the core of (CV) increase, more innovation promoting the accumulation of subsequent innovation of the enterprise itself, but when the core degree is increased to a certain level, the impact of innovation accumulation on enterprise innovation has been brought into full play. If we increase the core degree at this time, we will reduce the impact of innovation accumulation on enterprise innovation performance.

Table 1. Summary and correlation statistics(Obs =690）

	Mean	S.D.	*Presample-5*	*Public*	*CC*	*BC*	*Density*	*CN*	*CV*
Presample5	106	602	1.00						
Public	0.45	0.50	0.18	1.00					
CC	0.81	0.08	-0.02	-0.10	1.00				
BC	2.42	25.9	-0.01	0.01	-0.08	1.00			
ND	0.02	0.01	-0.05	-0.08	0.69	-0.03	1.00		
CN	13.5	4.16	0.07	-0.01	-0.12	-0.06	-0.63	1.00	
CV	1.68	1.40	-0.05	-0.11	0.18	0.04	0.10	-0.01	1.00
$Patents_{it+2}$	75.92	404.9							

Table 2. Negative binomial regression models with random effects（Obs=690）

Variables	$Patents_{it+2}$					
	1	2	3	4	5	6
Presample5	0.003***	0.002***	0.002***	0.002***	0.002***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Public	2.001***	2.071***	2.078***	2.085***	2.046***	0.703***
	(0.127)	(0.129)	(0.128)	(0.130)	(0.129)	(0.117)
CC	0.403	-1.547	-1.700	-1.587	-1.391	-0.734
	(1.078)	(1.302)	(1.291)	(1.304)	(1.325)	(1.073)
BC	-0.001	-0.001	-0.001	-0.001	-0.001	-0.003
	(0.004)	(0.004)	(0.003)	(0.004)	(0.004)	(0.003)
ND	-21.53***	1.191	5.355	0.700	0.123	-3.512
	(6.604)	(10.928)	(10.975)	(10.944)	(10.853)	(9.118)
CN		0.068***	0.076***	0.059**	0.073***	0.030*
		(0.025)	(0.024)	(0.028)	(0.025)	(0.018)
*public * CN*			-0.068**			
			(0.031)			
*Presample5 * CN*				0.005		
				(0.007)		
CV					0.160	0.106
					(0.154)	(0.147)
CV^2					-0.034**	-0.007
					(0.016)	(0.018)
*LNpresample5 * CV*						0.632***
						(0.030)
LNpresample5 * CV^2						-0.093***
						(0.007)
Constant	1.858**	2.105**	2.034**	2.264***	1.830***	2.445***
	(0.809)	(0.823)	(0.816)	(0.855)	(0.831)	(0.675)
$LR\text{-}chi^2(n)$	555.66	563.14	568.01	563.02	569.84	961.47
$Prob>chi^2$	0.000	0.000	0.000	0.000	0.000	0.000
loglikelihood	-2571.55	-2567.81	-2565.38	-2567.58	-2564.46	-2368.65

Note. Significant at* $p<0.1$，** $p<0.05$，***$p<0.01$(two-tailed tests for all variables); Standard deviations are in parentheses.

Table 3. Results of the negative binomial regression when public=0 and public=1

Variable.	$Patents_{it+2}$	
	Public=0（n=378）	*Public*=1（n=312）
Presample5	0.027***(0.004)	0.001***(0.000)
CC	-4.296***(1.425)	-0.840(2.258)
BC	-0.003(0.003)	-0.011(0.011)
Density	18.407*(11.400)	5.867(21.205)
CN	0.079***(0.028)	0.058 (0.040)
Constant	3.500***(0.918)	3.868***(1.337)
$LR\text{-}chi^2(n)$	233.92	130.00
$Prob>chi^2$	0.000	0.000
loglikelihood	-1002.14	-1511.39

Note. Significant at* $p<0.1$，** $p<0.05$，***$p<0.01$(two-tailed tests for all variables); Standard deviations are in parentheses.

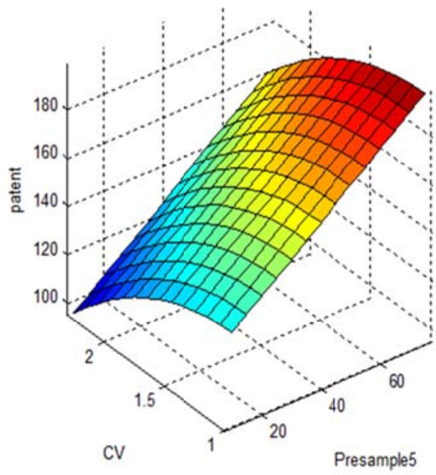

Figure 1. Moderating effect of coreness values

5. Conclusions and Implications

With the intensification of market competition, the competition between enterprises at the individual level has been gradually transformed into the network level competition based on clique units. The cooperation mechanism, path selection and market share within the factions will all affect the competitiveness and interests of the clique enterprises, and it even has an important impact on the awareness, behavior, and performance out of clique enterprises. Besides, the company is listed or not listed has a negative moderating effect on the number of clique groups affecting corporate innovation, which indicates that more capital of listed companies, more innovation depends on their own innovative capital investment, rather than from the factional group's cooperation to grab the innovation resources. However, for the non-listed companies, their innovative resources are mainly based on the knowledge sharing of cooperation among enterprises because of their own capital constrains.

Hypothesis 3 is not verified, the accumulation of innovation does not have the moderating effect on the impact of the clique number on the enterprise innovation, and that is, the accumulation of enterprise innovation will not affect the relationship between the clique number and the enterprise innovation. The possible explanations is that no matter how much innovation accumulation the enterprise has, it will only share and communicate knowledge in the field of cooperation, and shield knowledge that does not involve the field of cooperation. On the other hand, the update of knowledge and technology is very fast, and the former innovation accumulation of the partners has little effect on the immediate innovation of the enterprise.

Considering the cohesive subgroup of enterprise embeddedness based on the individual center network, we should consider the number of alliance relationships and the appropriate coreness values of enterprises, which can effectively enhance the innovation capability of enterprises. Less alliance relationship may make information exchange between enterprises inconvenient, and even stop the effective flow of some key innovative resources. But more alliance relations not only make the knowledge gained by the enterprise become consistent and redundant, but also make enterprise worry that their core knowledge will spillover quickly due to frequent external alliance of partners, in order to avoid increasing unnecessary market competition, enterprises will consciously reduce the sharing and communication of knowledge, these behaviors are not conducive to the effective acquisition of external innovation resources by the embedded enterprises. Therefore, when embedding an alliance innovation network, enterprises should not only strive to embed the network with more factions, but also take full account of the k-core of the cohesive subgroup that they are involve in, choosing to embed a cohesive subgroup with a moderate scale relationship.

Strategic alliance as an important way of knowledge sharing and communication among enterprises, the relevant government departments should encourage the establishment of mutually beneficial alliance relations among enterprises, form a closely cooperative factional group, and improve the level of enterprises to acquire innovative resources. On the one hand, we should improve the laws and regulations for the protections of intellectual property rights, establish the trust mechanism of enterprises, provide a good social environment for cooperation and innovation, and curb opportunistic behavior and "free riding" phenomenon in alliance cooperation; on the other hand, we should encourage inter-firm cooperation to focus on the diffusion of innovative products and technology, on the promise of ensuring that intellectual property rights are not infringed, the spillover effect of innovation is emphasized to promote the rapid economic development and promote the progress of the society.

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