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Industrial Innovation Ecosystem of Intelligent Connected Vehicles in China-Innovation Network and Niche Perspectives on Performance

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ABSTRACT:*Under the digital transformation, the traditional automobile industry is upgraded to the intelligent connected vehicle (ICV) industry, which provides strategic opportunities for China to become a powerful automobile country. Innovation network and innovation niche are two important factors in the evolution of innovation ecosystem of ICV industry. Based on the ICVs' ecological connotation, composition and characteristics, this study constructed the innovation ecological networks of this industry in China from 2008 to 2018, and then analyzed the network structure characteristics (mainly network centrality). Meanwhile, the concepts and the co-evolutionary aspects both technological niche width and overlap were researched. The results indicate that for innovation subjects with high technological niche width and low technological niche overlap, innovation network centrality has a more positive impact on collaborative innovation performance. Therefore, the theoretical and practical significance of the study is discussed, aiming to provide research basis for the improvement of innovation performance of ICV industry.*

KEY WORD*: Intelligent connected vehicle; Innovation ecosystem; Network centrality; Niche width & overlap; Innovation performance; China*

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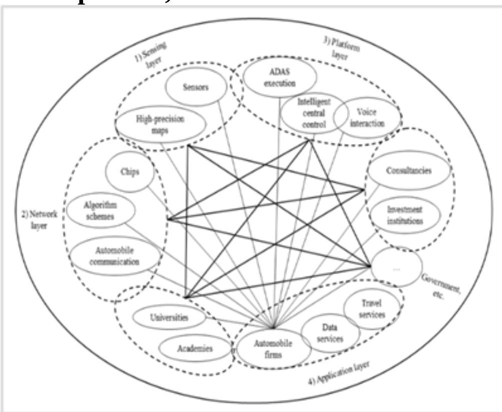
I. INTRODUCTION

Intelligent connected vehicles (ICVs) is defined as the new generation of vehicle ultimately replacing person to accomplish safe, comfortable, energy-saving, high-efficient driving, which refers to the organic combination of internet of vehicles and intelligent vehicle, equipped with advanced vehicle sensors, controllers, actuators and other devices, as well as modern communication and network technologies to realize intelligent information exchange and sharing between vehicles and person-vehicle-road-platform[1][2]. In digital economy, the automobile industry carries out product innovation through digital technology application, especially ICVs, to solve the pain point, transforming and upgrading traditional economy into digital economy of the industry. ICV is an organic combination of internet of vehicle (IoV) and intelligent vehicle. ICVs not only vertically expand the supply chain of traditional automobile firms up and down, but also horizontally expand the supply chain of non-traditional automobile firms, such as Internet industry and communication industry of IoVs. Meanwhile, in China, from 2011 to 2018, nearly 20 policies related to the ICV industry were launched at national level, and the contents mainly involve the top-level design of industrial strategy, cross-industry integration, formulation of industry standard system, the layout of technology R&D, pilot test of IoVs, establishment of intelligent data platform, construction of 5G network infrastructure, and market-oriented application of automatic driving. China's policies vigorously catalyze demand release, and the ICV industry has formed an innovation ecosystem[3]. Thus, ICV industry innovation ecosystem is in the process of ICV R&D innovation, an ecological system of multi-agent across organizational boundaries, collaboration and competition, self-organization and co-evolution, formed by innovation subjects (including vehicles manufacturing firms, parts R&D firms, Internet firms, start-ups, universities and research institutions, government departments, consultants and investment institutions), for breaking through the bottleneck of automated driving technology and realizing the fusion coordination of person-vehicle-road interaction[4][5] (Figure 1).

Figure 1:The cross population and community in ICV industrial innovation ecosystem: symbiosis, competition, and collaboration



Source: Author,the same below.

II. Research Design

2.1 Data Collection

The research data mainly comes from the Stata Intellectual Property Office database (SIPO). First, through adding and deleting the keyword sequences, the keywords including intelligent connected vehicle or intelligent vehicle or internet of vehicle or automatic driving, et al are most comprehensive. Second, 23396 patent applications for ICVs were from 2008 to 2018, after screening and deduplication, a total of 604 patents were obtained from two or more patent applicants (or patentees) (Figure 2), with 427 applicants (Figure 3).

Figure 2:The trend of the number of innovation subjects and collaborative patents in China:2008 to 2018

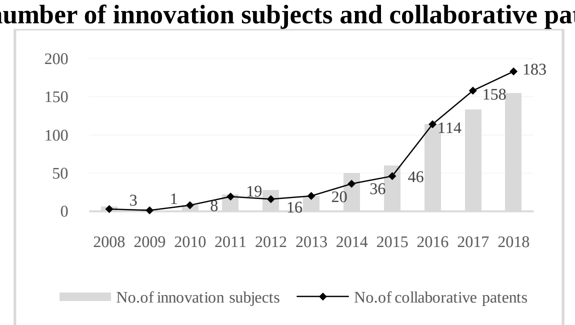
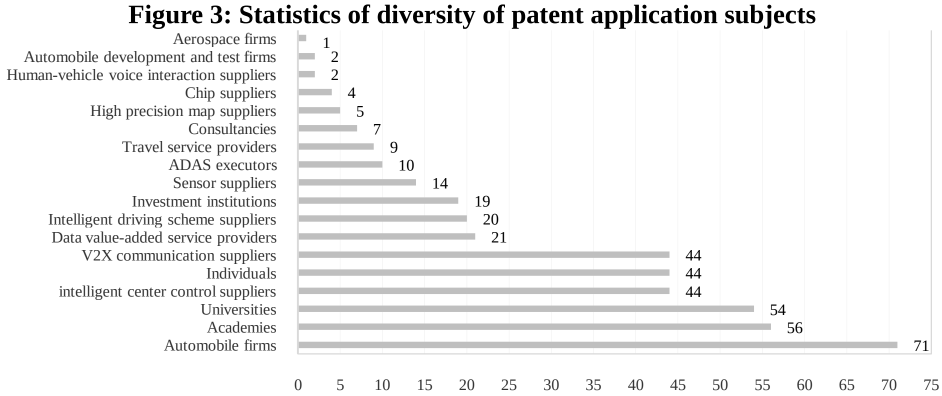


Figure 3: Statistics of diversity of patent application subjects



2.2 Evolution Analyses of Innovation Ecosystem

The patent collaboration networks divided by three stages are drawn through Ucinet6.5, as shown in Figure 4. At the same time, this paper takes a 3-year cycle (2008 to 2010, 2009 to 2011, …, 2016 to 2018) to build 9 cooperation networks in 2010 to 2018, and make statistics on the network structures and technology niches evolution characteristics of each year see Table 1.

2.2.1 Network Structure

a) **Warm-up period**: The number of subjects in the ecosystem is small, the frequency of cooperation is small, and the collaboration relationship between two partners is such much that the subjects are less connected, and the diversity of subjects is low, and the collaboration type is single, mainly Firm-University-Research patent collaboration dominated by automobile firms.

b) **Exploratory period**: The number of subjects integrated into ecosystem has increased gradually, but most of them are bilateral collaboration, and the stable triangle relationship of innovation communities accounts for a small proportion, and there are still innovation islands.

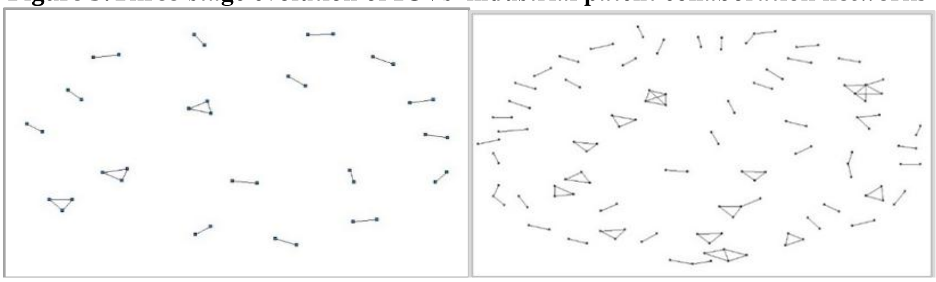
c) **High-speed development period**: The subjects increase distinctly, the frequency high and the diversity rich. Figure 5c, the nodes of automobile firms, universities and research institutes are large, indicating that the innovation activities are led by the Firm-University-Research cooperation, which drives multiple subjects of other industries in ICVs' industry to create and exchange values, and promotes the positive evolution and sustainable development of the innovation ecosystem.

Among them above, the centrality of an innovation subject is an index to measure the activity ability of a subject in innovation networks, which represents the absolute degree of the subject obtaining resources directly. The measure formula is

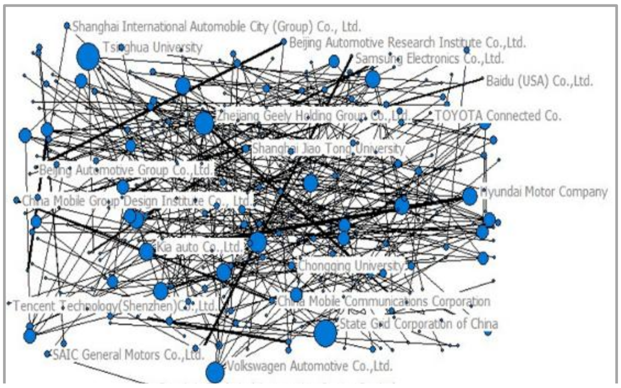
$$C_D(N_i) = \sum_{j=1}^{n} a(i,\ j)\ (i \neq j)^{[6]}$$

where, $C_D(N_i)$ represents the degree of centrality of the innovation subject i, n represents the total number of all the innovation subjects in the network, and $a(i,j) = 1$ represents that the subject i and another one j jointly as applicants for a patent, otherwise,$a(i,j) = 0$. This study calculates the average level of subjects' centrality in each year, which reflects the changing trend of the core subject in the innovation ecosystem see table 1.

Figure 5:Three-stage evolution of ICVs' industrial patent collaboration networks



(a) Warm-up period (2008 to 2011)(b) Exploratory period (2012 to 2015)



(c) High-speed development period (2016 to 2018)

Table 1:Evolution characteristics of patent cooperation network structures and technology niches of ICVs' industry

Year	Warm-up period		Exploratory period				High-speed development period		
	2010	2011	2012	2013	2014	2015	2016	2017	2018
Network size	17	33	56	63	85	113	118	263	347
No. of network edge	20	42	76	84	124	162	338	442	606
Network density	0.074	0.04	0.025	0.022	0.017	0.013	0.010	0.006	0.005
Centrality	1.176	1.2727	1.357	1.333	1.459	1.434	1.798	1.681	1.746
Technology niche width	32.851	21.385	27.381	38.450	33.171	38.275	32.759	31.300	32.301
Technology niche overlap	0.602	0.444	0.736	0.568	0.640	0.586	0.593	0.604	0.626
IPC subclass category	107	97	110	114	118	120	121	124	123

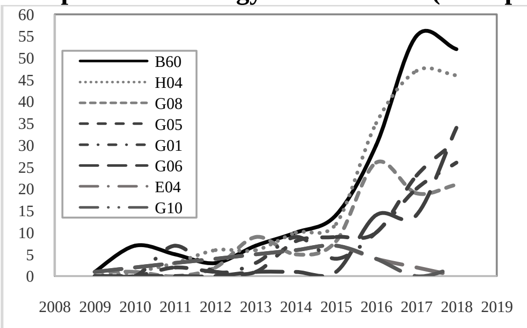
Note: The centrality, technology niche width and overlap are the average level, and IPC subclass category is the total number of all IPC subclass categories in each year.

2.2.2 Technological Niche

Technology niche is an ecological space feature that the innovation subject achieves a balance in the acquisition,utilization and competition of technological resources, including the width and overlap of technology niche. The technology niche width is defined as the type and scape of technology domain owned and utilized by the innovation subject in the innovation ecosystem[7], which refers the width of technology accumulation and the degree of knowledge diversification of technology R&D; the technology niche overlap is defined as the proportion to the similar distribution of technology resources or to the same types of technology fields between subjects, which reflects the degree of interdependence of subjects to common technology resources.[8]

a) **Technology R&D category**: The top 8 International Patent Classification (IPC) categories are selected for applications in ICVs' field in Figure 6. The subjects focus on the R&D of automatic driving technologies, such as intelligent internet vehicle driving control method and system, communication control system, safe driving monitoring system (B60), and ICV cloud operating system, remote communication method and system, cloud platform security implementation methods (H04), shows a sharp upward trend from 2015 and peaks in 2017. Meanwhile, ICVs' simulation test (G05), multi-source perceptual positioning (G01), data privacy protection method and system (G06) also are focused.

Figure 6:The trend of patent technology R&D of ICVs (the top 8 IPC categories)



b) **Technology niche width**: The niche width is measured by the number of IPC subclass categories applied for patents by the innovation subjects in each year that represents the technical domains, which can reflect the knowledge base of the technology R&D and cooperation of the innovation subject.

c) **Technology niche overlap**: This study uses the average value of technology niche overlap between the subject i and all other subjects that produce patent cooperation every year to measure technology niche overlap. Using the Pianka formula (symmetric α method)[8]to measure technology niche overlap, can reflect the degree of competition.

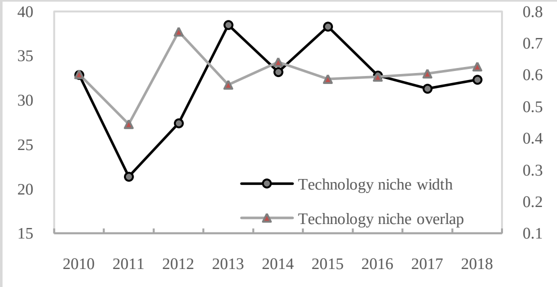
$$TNO_{ij} = \sum_{r=1}^{R} P_{ir} P_{jr} / \sqrt{\sum_{r}^{R} (P_{ir})^2 \sum_{r}^{R} (P_{jr})^2}$$

where, TNO_{ij} represents the niche overlap degree between the subject i and$j$, P_{ir} and P_{jr} respectively is the proportion of the subject i and$j$ in the r-th technology field to the total number (R) of all technology fields.

$$TNO_i = \sum_{j=1}^{N} TNO_{ij} / N$$

where, TNO_i represents the degree of technology niche overlap of the subject i, N is the number of subjects that the subject i cooperates with in each year. This study calculates the average level of technology niche width and overlap in Table 1, and draws the trend comparison graph of them in Figure 7.

Figure 6: The trend of technology niche evolution



d) **Warm-up period & High-speed development period**: Technology niche width and the degree of niche overlap have the same evolutionary characteristics, indicating the subjects in ecosystem seek for partners with higher degree of technology similarity, and jointly overcome the special problems of technology R&D.

e) **Exploration period**: Technology niche width and overlap have the characteristics of reciprocal evolution, indicating that at different stages, the innovation subject may mainly adopt differentiated technology R&D strategy, component strategy and win-win, and carry out patent market layout to maintain competitive advantages.

III. Impacts of Network Structure and Technological Niche Evolution on Innovation Performance

3.1 Descriptive Statistics

Descriptive statistical analysis results in Table 2, and the maximum value of the variance expansion factor (VIF) of all models is 2.96, which is less than the critical value of 3.00, there is no serious multicollinearity problem between variables.

Table 2: Descriptive statistical analysis

Variables	Mean	SD	1	2	3	4	5	6	7	8	9	10	11
Collaborative innovation	2.180	2.162	1.000										
Age	26.034	28.805	-0.025	1.000									
State-owned	0.249	0.433	-0.026	0.294***	1.000								
Foreign-found	0.256	0.437	0.053	0.253***	0.338***	1.000							
Eastern region	0.625	0.485	0.097**	0.296***	0.097**	0.469***	1.000						
Middle region	0.069	0.254	0.092**	0.068	0.148***	0.160***	0.352***	1.000					
Northeast region	0.013	0.112	-0.018	0.022	0.109**	-0.066	0.146***	-0.031	1.000				
Network density	0.011	0.008	0.093**	0.096**	0.035	0.035	-0.005	0.086*	0.005	1.000			
Centrality	1.539	0.960	0.200***	0.185***	0.015	0.122***	-0.088*	0.002	-0.024	0.124***	1.000		
Technology niche width	32.853	32.328	0.144***	0.515***	0.365***	0.123***	-0.058	0.021	-0.001	0.023	0.268***	1.000	
Technology niche overlap	0.610	0.299	0.173***	0.180***	-0.074	-0.056	0.230***	0.137***	-0.064	-0.035	0.092**	0.054	1.000

Note: * p < 0.1, ** p < 0.05, *** p < 0.01

3.2Collaborative Innovation Performance

The variance of performance is greater than the mean (mean=2.180, variance=4.674), in order to avoid deviation caused by excessive dispersion in the regression analysis, the Poisson model is therefore rejected, a negative binomial regression model is adopted for data analysis [9] in Table 3.

Table 3: Relationships between centrality and technology niche on collaborative innovation performance

Variables/Models	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
	Full samples	Full samples	Low tech-niche width	High tech-niche width	Low tech-niche overlap	High tech-niche overlap
Age	-0.000 (-0.20)	-0.001 (-0.64)	-0.004 (-1.30)	-0.002 (-0.72)	0.001 (0.53)	-0.003 (-1.07)
State-owned	0.058 (0.51)	0.061 (0.54)	0.252* (1.86)	-0.230 (-1.18)	-0.152 (-0.94)	0.154 (1.03)
Foreign-found	0.168 (1.25)	0.151 (1.14)	0.107 (0.62)	0.149 (0.70)	0.018 (0.08)	0.223 (1.38)
Eastern region	0.238* (1.94)	0.239** (1.97)	0.269* (1.81)	0.186 (0.93)	0.301 (1.45)	0.178 (1.14)
Middle region	-0.030 (-0.15)	-0.059 (-0.29)	0.068 (0.28)	-0.165 (-0.46)	0.038 (0.14)	-0.294 (-0.90)
Northeast region	0.117 (0.30)	0.137 (0.36)	-0.012 (-0.02)	0.293 (0.49)	0.317 (0.76)	-0.700 (-0.65)
Network density	-15.058*** (-2.84)	-12.003** (-2.27)	-1.985 (-0.31)	-28.667*** (-3.27)	-2.641 (-0.35)	-16.993** (-2.35)
Centrality		0.144***	-0.081	0.162***	0.211***	0.095*

		(3.58)	(-1.04)	(3.24)	(3.91)	(1.66)
Constant	2.247*** (6.29)	2.222*** (5.29)	2.987*** (3.39)	2.968*** (2.95)	2.198*** (3.00)	2.166*** (4.04)
Number of observations	477	477	294	183	231	246
LR test	43.450***	39.720***	9.590***	19.540***	7.270***	13.170***
Chow test			0.003***		0.022**	

a) **Model 2**: The centrality has a positive impact on collaborative innovation performance (b=0.144, p<0.01).

b) **Model 3 & 4**: Technology niche width is at high level, the centrality of a subject has a more significantly positive effect on performance (b=0.162>0.144, p<0.01).

c) **Model 5 & 6**: The lower the technology niche overlap level is, the more distinctly positive effect the centrality on collaborative innovation performance has (b=0.211>0.144, p<0.01).

IV. Conclusions

Based on the patent data of ICVs' industry in China from 2008 to 2018, this study constructs its innovation network structures, analyzes the composition, diversity, dynamic evolution of innovation subjects, reveals the staged dynamic evolution characteristics of a subject's technology niche width and overlap, and explores the impacts of interaction between network structures and technology niche on innovation performance.

There are several interesting directions for future studies, except some limitations. this study solely analyzed the position and function of innovation subjects in technology ecosystem from the innovation centrality and niche. Future studies might investigate the form of cross-network, that is cross-realm transposition.[10] And it needs to explore what the important roles innovation subject plays is in two ecosystem, such as top partner, anchor tenant, keystone player, etc.[11]

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