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The Technological Distance Between Chinese Firms: Deepening and Diversifying Technologies

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Abstract: This study measures the technological distance between firms within and across industries as a case study of Chinese firms to investigate firms' technology accumulation patterns. Specifically, cosine similarity is used to compare the technology positions generated by the patent applications of Chinese firms. The analysis shows that as the number of patent applications increases, firms tend to deepen the technological characteristics of each industry and firm while broadening the variety of technological fields. As a result, although the quantity and quality of technologies are critical, understanding the characteristics of technologies as a technological structure or system that differs from one firm to another is also crucial.

JEL classification: O3, L1, L2

Keywords: technological distance, technology position, patent

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The Technological Distance Between Chinese Firms: Deepening and Diversifying Technologies*

Koichiro Kimura†

1. Introduction

Firms accumulate technologies that will boost their competitiveness in the face of fierce competition and technological change. They seek to differentiate themselves technologically from their competitors in the same industry while also incorporating their competitors' technologies. As a result, firms' technological positioning will move closer or further away from each other in competition within the same industry. In addition, they strive to be the first to adopt technologies from different industries to differentiate themselves technologically or to follow what their competitors are adopting. Consequently, the firms' technological positioning will be somewhat closer to that of firms in various industries that they have adopted. What patterns of change in technological distance or proximity between firms' technology positions can be observed within and across industries?

Many studies on technological distance have been conducted. The related studies can be broadly classified based on the methods of measurement and creating vectors for technology positions, and their applications. Cosine similarity has been

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widely used to measure technological distance (Jaffe, 1988), but Mahalanobis distance, which accounts for collocation between technologies, has also been used (Bloom et al., 2013). Subsequently, for vector elements, the following have often been used: the amount of research and development expenditures and the number of patents or patent applications in each technological field, or the results of natural language processing (NLP) of patent or patent application documents. Finally, for the applications of measurement results, technological distance has frequently been used to verify technology spillovers between industries or firms that are close in technological distance (Bloom et al., 2013; Forman and van Zeebroeck, 2019; Jaffe, 1988), but it has also been used for other purposes. For example, Motohashi and Zhu (2020) analyzed technological catch-up between two firms in an industry using cosine similarity between vectors obtained through NLP. Kimura et al. (2022) compared the processes of firms' technology accumulation based on cosine similarity between vectors generated by the number of patent applications in each technological field and NLP. Thus, previous research has shown that industries or firms in similar technology positions influence each other in terms of technology accumulation and how the technological distance between firms or patents within the same industry is changing.

However, how the technological distance between firms has changed compared with other firms in different industries remains unclear. Even within the same industry, the technological distance can vary from firm to firm, depending on each firm's background and business strategy. Furthermore, average technological distance states in each industry can vary from industry to industry, depending on technological conditions or industry trends.

Therefore, this study analyzes the technological distance between Chinese firms in several industries that have seen a rapid increase in the number of patent applications. In particular, the technological fields each firm focuses on are compared with firms within and across industries. This study shows that as the number of patent applications increases, firms tend to deepen the technological characteristics of each industry and firm while broadening the range of technological fields. In other words, firms are attempting to boost their competitiveness by combining diverse technologies rather than focusing on specific technological fields.

The structure of this paper is as follows. Section 2 introduces the methods. Section 3 presents the results of the analysis. Finally, Section 4 summarizes, and concludes the analysis.

2. Methods

The cosine similarity measures the technological distance between firms in this study. Let $\mathbf{F}^A$ and $\mathbf{F}^B$ be the technology positions of firms with elements F_k^A and F_k^B as the fractions of patent applications in each technology field k filed by Firms A and B, respectively. The cosign similarity s^{AB} between Firms A and B is as follows:

$$s^{AB} = similarity(\mathbf{F}^A, \mathbf{F}^B) = \frac{\sum_{k=1}^{m} F_k^A F_k^B}{\sqrt{\sum_{k=1}^{m} (F_k^A)^2} \sqrt{\sum_{k=1}^{m} (F_k^B)^2}}.$$

The similarity indicates 1 if the angle between the two technology positions is the same and 0 if it is orthogonal.[1] In the next section, the following two measurement methods are used.

2.1. Similarity 1: Similarity Between Technology Positions by Point in Time

Subsection 3.1 measures the technological distance between firms based on technology positions at each point in time. Let $\mathbf{F}_{\leq t}^A$ and $\mathbf{F}_{\leq t}^B$ be the technology positions of firms, composed of the cumulative number of patent applications up to time t filed by Firms A and B, respectively. Then, the cosign similarity $s_{\leq t}^{AB}$ between Firms A and B is

$$s_{\leq t}^{AB} = similarity(\mathbf{F}_{\leq t}^A, \mathbf{F}_{\leq t}^B).$$

This study makes use of patent data from 22 major firms in the following seven industries: construction machinery, automotive, home appliance, smartphone, telecommunications equipment, Internet services, and artificial intelligence (AI) (Table 1). This study compares firms in various industries, ranging from those with a strong element of machinery-related technology to those with a strong element of information and communication technology (ICT). The patent data are patent applications filed in China by December 31, 2020, and were downloaded from CNIPR, the intellectual property database published by Intellectual Property Publishing House in China, in

[1] The vector elements in this study are 0 or positive. However, if the elements of vectors are negative, the similarity can also be negative.

November 2022.[2] To overview the period when the number of patent applications began increasing rapidly, time *t* is set to 2005, 2010, 2015, and 2020. The elements of technology positions here are composed of technological field codes assigned to each patent application by the International Patent Classification (IPC), specifically the subclass level. For example, a subclass, "H04L: Transmission of digital information," is in the class "H04: Electric communication technique," which is in the section "H: Electricity."

Table 1: The cumulative number of a firm's patent applications and technological fields, 2005, 2010, 2015, and 2020

	2005		2010		2015		2020	
	(Applications)	(Feilds)	(Applications)	(Feilds)	(Applications)	(Feilds)	(Applications)	(Feilds)
Construction machinery industry								
Sany	10	6	213	53	1,310	122	2,583	170
XCMG	2	2	115	32	1,324	112	3,173	183
Zoomlion	3	2	80	26	2,234	138	2,920	158
Automotive industry								
BYD	235	68	1,717	163	3,830	213	9,642	278
Dongfeng	26	17	125	57	716	126	4,457	200
FAW	4	4	60	31	428	98	2,578	184
Geely	5	4	183	60	1,610	155	4,294	197
SAIC	21	19	184	64	1,193	140	4,387	187
Home appliance industry								
Haier	207	37	857	83	4,065	158	19,219	222
Hisense	73	15	454	60	2,534	106	7,931	163
Midea	10	6	204	38	4,288	137	19,330	219
TCL	67	20	687	69	7,028	177	13,410	216
Smartphone industry								
Oppo	-	-	16	12	4,494	94	25,086	184
Vivo	-	-	-	-	288	33	12,380	124
Telecommunications equipment industry								
Huawei	2,647	47	12,654	79	32,358	141	65,993	221
ZTE	3,148	56	19,599	94	46,837	154	85,362	215
The Internet services industry								
Alibaba	2	2	315	10	4,088	37	18,574	112
Baidu	-	-	139	7	3,060	59	14,929	115
Tencent	310	13	1,658	20	9,264	55	28,889	100
Artificial intelligence (AI) industry								
Megvii	-	-	-	-	72	10	834	41
SenseTime	-	-	-	-	53	4	1,771	34
Yitu	-	-	-	-	14	4	398	18

Source: Author's calculation based on CNIPR.

[2] Firms are searched based on the CNIPR's applicant dictionary and thus broadly include firms aggregated based on names, and affiliated firms.

2.2. Similarity 2: Similarity Between New and Old Technology Positions

Subsection 3.2 then measures the technological distance between firms based on new and old technology positions to decompose the change in distance caused by Similarity 1. First, this study assumes that Firm *A* is the firm whose distance from the others is being measured. Next, let $\mathbf{F}_t^A$ be the new technology positions of firms, composed of the number of patent applications past time *t* – 1 and up to time *t* filed by Firm *A*. Additionally, let $\mathbf{F}_{\leq t-1}^A$, $\mathbf{F}_{\leq t-1}^B$, and $\mathbf{F}_{\leq t-1}^{B^*}$ be the old technology positions of firms, composed of the cumulative number of patent applications up to time *t* – 1 filed by Firm *A*, Firm *B* in the same industry, and Firm *B* in the other industry, respectively. Then, the cosign similarity s_t^{AA} between Firm *A* and its own old state, the cosine similarity s_t^{AB} between Firm *A* and Firm *B*'s old state in the same industry, and the cosine similarity $s_t^{AB^*}$ between Firm *A* and Firm *B**'s old state in the other industry are as follows:

$$s_t^{AA} = similarity(\mathbf{F}_t^A, \mathbf{F}_{\leq t-1}^A),$$

$$s_t^{AB} = similarity(\mathbf{F}_t^A, \mathbf{F}_{\leq t-1}^B),$$

and

$$s_t^{AB^*} = similarity(\mathbf{F}_t^A, \mathbf{F}_{\leq t-1}^{B^*}).$$

Depending on the size of each firm's s_t^{AA}, s_t^{AB}, or $s_t^{AB^*}$, the changes in $s_{\leq t}^{AB}$ of each pair in the same industry can be decomposed into the following four movements. The first two movements are examples of technological distance decreasing as both firms in the same industry accumulate technologies in similar technological fields, whereas the second two movements are examples of technological distance increasing as only one firm accumulates technologies in different technological fields (Table 2).

Table 2: The four movements to change the technological distance

	Technologies inside of the industry	Technologies outside of the industry
Decreasing the technological distance: Accumulation by both firms	(1) Commonization	(2) Transformation
Increasing the technological distance: Accumulation by only one firm	(3) Deepening	(4) Widening

Source: Author's own work.

The first two movements are as follows. The first is commonization, which occurs when both or one of s_t^{AB} of each pair in the same industry become larger. As a result, the technological fields of both firms in the same industry would further overlap by filing in the existing fields inside that industry. The second is transformation, which occurs when both of $s_t^{AB^*}$ of each pair in the same industry become larger. Again, the technological fields of both firms in the same industry would overlap, but this time, by filing in fields outside that industry. This movement is similar to commonization in that the technological distance decreases, but the transformation is used here to emphasize the technological shift in terms of technological fields.

The following are the second two movements. The third is deepening, which is when both or one of s_t^{AA} of each pair in the same industry become larger. As a result, the technological fields of both firms in the same industry would be further separated by filing in the existing fields within that industry. The fourth is widening, which occurs when only one of $s_t^{AB^*}$ of each pair in the same industry becomes larger. Again, the technological fields of both firms in the same industry would be separated, but this time by filing in fields outside of that industry.

3. Analysis

3.1. Similarity 1: Similarity Between Technology Positions by Point in Time

Table 3 reports the results of Similarity 1. The value of the technological distance is the same whether $s_{\leq t}^{AB}$ is based on Firm *A* or Firm *B*; hence, it is only listed below the

diagonal line of the technological distance from itself, that is, 1.00, in the blue cell.[3] The cell is red if the technological distance is equal to or greater than 0.50. The seven industries' boundaries are delineated by bold lines.

Table 3: The technological distance between cumulative applications, 2005, 2010, 2015, and 2020

(a) 2005

	Sany	XCMG	Zoomlion	BYD	Dongfeng	FAW	Geely	SAIC	Haier	Hisense	Midea	TCL	Oppo	Vivo	Huawei	ZTE	Alibaba	Baidu	Tencent	Megvii	SenseTime	Yitu
Sany	1.00																					
XCMG	0.58	1.00																				
Zoomlion	0.00	0.32	1.00																			
BYD	0.00	0.00	0.00	1.00																		
Dongfeng	0.00	0.00	0.00	0.10	1.00																	
FAW	0.00	0.00	0.00	0.01	0.35	1.00																
Geely	0.00	0.00	0.00	0.01	0.10	0.00	1.00															
SAIC	0.00	0.00	0.00	0.08	0.42	0.30	0.00	1.00														
Haier	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.01	1.00													
Hisense	0.00	0.00	0.00	0.04	0.14	0.00	0.00	0.01	0.22	1.00												
Midea	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.08	0.01	0.00	1.00											
TCL	0.00	0.00	0.00	0.08	0.12	0.03	0.00	0.03	0.14	0.92	0.01	1.00										
Oppo	-	-	-	-	-	-	-	-	-	-	-	-	-									
Vivo	-	-	-	-	-	-	-	-	-	-	-	-	-	-								
Huawei	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.05	0.19	0.00	0.29	-	-	1.00							
ZTE	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.05	0.20	0.00	0.30	-	-	1.00	1.00						
Alibaba	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.07	0.10	0.00	0.05	-	-	0.66	0.65	1.00					
Baidu	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
Tencent	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.07	0.23	0.00	0.18	-	-	0.84	0.83	0.91	-	1.00			
Megvii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
SenseTime	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Yitu	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(b) 2010

	Sany	XCMG	Zoomlion	BYD	Dongfeng	FAW	Geely	SAIC	Haier	Hisense	Midea	TCL	Oppo	Vivo	Huawei	ZTE	Alibaba	Baidu	Tencent	Megvii	SenseTime	Yitu
Sany	1.00																					
XCMG	0.46	1.00																				
Zoomlion	0.44	0.82	1.00																			
BYD	0.03	0.04	0.01	1.00																		
Dongfeng	0.17	0.28	0.15	0.18	1.00																	
FAW	0.14	0.11	0.02	0.21	0.54	1.00																
Geely	0.05	0.17	0.05	0.22	0.52	0.37	1.00															
SAIC	0.07	0.14	0.03	0.34	0.65	0.41	0.50	1.00														
Haier	0.01	0.00	0.00	0.04	0.02	0.01	0.01	0.03	1.00													
Hisense	0.02	0.00	0.00	0.16	0.10	0.01	0.03	0.06	0.20	1.00												
Midea	0.02	0.00	0.01	0.03	0.02	0.07	0.01	0.03	0.27	0.15	1.00											
TCL	0.03	0.00	0.00	0.20	0.09	0.04	0.03	0.06	0.12	0.89	0.05	1.00										
Oppo	0.03	0.00	0.00	0.16	0.02	0.01	0.02	0.08	0.08	0.49	0.01	0.53	1.00									
Vivo	-	-	-	-	-	-	-	-	-	-	-	-	-	-								
Huawei	0.05	0.00	0.00	0.04	0.01	0.00	0.02	0.04	0.05	0.28	0.03	0.41	0.26	-	1.00							
ZTE	0.05	0.00	0.00	0.04	0.01	0.00	0.02	0.04	0.05	0.29	0.03	0.42	0.26	-	0.99	1.00						
Alibaba	0.03	0.00	0.00	0.09	0.00	0.00	0.03	0.06	0.07	0.32	0.03	0.35	0.55	-	0.63	0.60	1.00					
Baidu	0.01	0.00	0.00	0.11	0.00	0.00	0.03	0.06	0.07	0.34	0.02	0.33	0.70	-	0.35	0.34	0.91	1.00				
Tencent	0.03	0.00	0.00	0.08	0.01	0.00	0.04	0.06	0.07	0.39	0.03	0.44	0.47	-	0.75	0.72	0.96	0.79	1.00			
Megvii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
SenseTime	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Yitu	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[3] Although the technological distance from itself was not defined in Section 2, it would be $s_{\leq t}^{AA}$ based on the notation in Similarity 1.

(c) 2015

	Sany	XCMG	Zoomlion	BYD	Dongfeng	FAW	Geely	SAIC	Haier	Hisense	Midea	TCL	Oppo	Vivo	Huawei	ZTE	Alibaba	Baidu	Tencent	Megvii	SenseTime	Yitu
Sany	1.00																					
XCMG	0.55	1.00																				
Zoomlion	0.60	0.93	1.00																			
BYD	0.08	0.06	0.05	1.00																		
Dongfeng	0.24	0.23	0.21	0.45	1.00																	
FAW	0.13	0.08	0.08	0.41	0.50	1.00																
Geely	0.18	0.15	0.12	0.39	0.82	0.32	1.00															
SAIC	0.21	0.16	0.16	0.46	0.84	0.47	0.81	1.00														
Haier	0.02	0.00	0.01	0.04	0.03	0.02	0.02	0.03	1.00													
Hisense	0.02	0.01	0.01	0.26	0.10	0.04	0.06	0.13	0.24	1.00												
Midea	0.03	0.01	0.01	0.04	0.05	0.03	0.03	0.05	0.43	0.29	1.00											
TCL	0.03	0.01	0.02	0.32	0.08	0.04	0.06	0.11	0.09	0.72	0.08	1.00										
Oppo	0.01	0.01	0.01	0.29	0.10	0.04	0.07	0.15	0.07	0.73	0.03	0.64	1.00									
Vivo	0.01	0.01	0.01	0.34	0.10	0.06	0.07	0.15	0.07	0.73	0.02	0.64	0.96	1.00								
Huawei	0.02	0.01	0.01	0.12	0.04	0.03	0.04	0.08	0.09	0.40	0.04	0.32	0.47	0.36	1.00							
ZTE	0.02	0.01	0.01	0.11	0.03	0.03	0.03	0.08	0.09	0.39	0.04	0.31	0.46	0.35	1.00	1.00						
Alibaba	0.02	0.01	0.01	0.23	0.09	0.04	0.07	0.14	0.08	0.54	0.04	0.46	0.78	0.75	0.61	0.57	1.00					
Baidu	0.01	0.02	0.01	0.25	0.10	0.04	0.07	0.15	0.07	0.55	0.04	0.47	0.84	0.82	0.47	0.43	0.96	1.00				
Tencent	0.02	0.01	0.02	0.22	0.08	0.04	0.06	0.14	0.09	0.58	0.04	0.47	0.77	0.72	0.69	0.66	0.98	0.92	1.00			
Megvii	0.00	0.00	0.00	0.08	0.02	0.01	0.01	0.04	0.02	0.24	0.01	0.17	0.21	0.19	0.09	0.09	0.20	0.20	0.20	1.00		
SenseTime	0.00	0.00	0.00	0.05	0.01	0.00	0.01	0.02	0.00	0.08	0.00	0.07	0.09	0.07	0.02	0.03	0.10	0.10	0.09	0.98	1.00	
Yitu	0.00	0.00	0.00	0.06	0.02	0.00	0.02	0.04	0.01	0.21	0.00	0.13	0.16	0.13	0.04	0.05	0.13	0.14	0.12	0.89	0.88	1.00

(d) 2020

	Sany	XCMG	Zoomlion	BYD	Dongfeng	FAW	Geely	SAIC	Haier	Hisense	Midea	TCL	Oppo	Vivo	Huawei	ZTE	Alibaba	Baidu	Tencent	Megvii	SenseTime	Yitu
Sany	1.00																					
XCMG	0.71	1.00																				
Zoomlion	0.56	0.89	1.00																			
BYD	0.13	0.11	0.08	1.00																		
Dongfeng	0.27	0.24	0.18	0.62	1.00																	
FAW	0.23	0.17	0.14	0.64	0.87	1.00																
Geely	0.22	0.17	0.12	0.61	0.87	0.80	1.00															
SAIC	0.26	0.21	0.17	0.61	0.91	0.91	0.91	1.00														
Haier	0.01	0.01	0.01	0.02	0.03	0.04	0.02	0.03	1.00													
Hisense	0.05	0.03	0.03	0.20	0.17	0.30	0.13	0.21	0.47	1.00												
Midea	0.02	0.01	0.01	0.03	0.04	0.04	0.03	0.05	0.60	0.51	1.00											
TCL	0.05	0.03	0.03	0.25	0.15	0.26	0.11	0.18	0.11	0.65	0.12	1.00										
Oppo	0.05	0.03	0.03	0.24	0.20	0.36	0.15	0.25	0.05	0.69	0.04	0.64	1.00									
Vivo	0.05	0.03	0.03	0.23	0.20	0.37	0.15	0.26	0.05	0.67	0.04	0.61	0.99	1.00								
Huawei	0.04	0.02	0.02	0.16	0.13	0.24	0.13	0.19	0.05	0.44	0.05	0.39	0.70	0.74	1.00							
ZTE	0.03	0.02	0.02	0.15	0.12	0.22	0.12	0.18	0.05	0.42	0.05	0.37	0.68	0.72	1.00	1.00						
Alibaba	0.06	0.05	0.04	0.23	0.24	0.45	0.18	0.32	0.05	0.56	0.04	0.48	0.71	0.75	0.54	0.51	1.00					
Baidu	0.06	0.05	0.04	0.24	0.26	0.48	0.19	0.32	0.05	0.58	0.04	0.50	0.73	0.76	0.45	0.42	0.95	1.00				
Tencent	0.06	0.04	0.04	0.23	0.23	0.44	0.17	0.30	0.06	0.63	0.05	0.53	0.75	0.79	0.62	0.59	0.97	0.94	1.00			
Megvii	0.06	0.02	0.03	0.13	0.12	0.23	0.10	0.17	0.03	0.32	0.02	0.24	0.38	0.33	0.20	0.18	0.41	0.51	0.45	1.00		
SenseTime	0.06	0.02	0.03	0.12	0.11	0.21	0.09	0.15	0.02	0.30	0.02	0.23	0.36	0.31	0.15	0.13	0.37	0.49	0.41	0.97	1.00	
Yitu	0.06	0.03	0.03	0.16	0.16	0.31	0.12	0.21	0.04	0.43	0.03	0.34	0.52	0.49	0.24	0.22	0.58	0.71	0.62	0.87	0.90	1.00

Source: Author's calculation based on CNIPR.

First, within the same industry, the technological distance narrows, with many values equal to or greater than 0.50. Therefore, the number of patent applications filed by each firm has increased, so has technology accumulation in the technological fields that form each industry's core. In other words, each industry has become more technologically specialized, and China's industrial structure has become more diverse.

However, the technological distance between home appliance firms is relatively great; additionally, the technological distance between Hisense and TCL, which are technologically close within the same industry, has become far. In this study, although home appliances are defined as a single industry, they can be broadly divided into white goods (e.g., washing machines, refrigerators, and air conditioners) and black

goods (primarily audiovisual equipment). As a result, the technological distance between the groups is relatively large if the home appliance firms are divided into one group of Haier and Midea, which primarily produce white goods, and another group of Hisense and TCL, which primarily produce black goods. However, even among black goods firms, note that the technological distance between Hisense, which is relatively close to white goods and Internet services firms, and TCL, which is not, has become more distant.

Subsequently, between industries, the technological distance between various industries has shrunk. Specifically, three distinct trends can be observed. First, the technological distance between the construction equipment industry and the automotive industry has grown a little closer. Second, the technological distance between the automotive industry and the following industries has narrowed: home appliance (black goods), smartphone, telecommunications equipment, Internet services, and AI. Third, the technological distance between the following industries has narrowed significantly: home appliance (black goods), smartphone, telecommunications equipment, and Internet services. Similarly, the technological distance between these industries and the AI industry has become much closer among some firms.

However, the technological distance between the telecommunications equipment and Internet services industry remains small but has grown slightly between 2005 and 2020. As the number of patent applications has increased, the technologies of both industries may have become more specialized in their respective fields.

Although this subsection has discussed technological distance and its changes, it does not specify the extent to which each firm approached the other. Therefore, the next subsection organizes the changes in the technological distance based on the four movements.

3.2. Similarity 2: Similarity Between New and Old Technology Positions

Table 4 reports the results of Similarity 2, specifically the technological distance between the new applications filed by each firm past time $t - 1$ up to time t (row) and the old applications filed by each firm up to time $t - 1$ (column). The values in the blue cells are s_t^{AA}, whereas those in the red cells are s_t^{AB} or $s_t^{AB^*}$ which is equal to or larger than 0.50. As in Table 2, the boundaries of the seven industries are delimited by bold lines.

Table 4: The technological distance between new and old applications, 2010, 2015, and 2020

(a) 2010

New Applications \ Previous Applications	Sany	XCMG	Zoomlion	BYD	Dongfeng	FAW	Geely	SAIC	Haier	Hisense	Midea	TCL	Oppo	Vivo	Huawei	ZTE	Alibaba	Baidu	Tencent	Megvii	SenseTime	Yitu
Sany	0.54	0.27	0.09	0.02	0.06	0.13	0.02	0.04	0.00	0.01	0.01	0.03	-	-	0.05	0.05	0.03	-	0.04	-	-	-
XCMG	0.37	0.74	0.36	0.04	0.17	0.03	0.03	0.16	0.00	0.00	0.01	0.00	-	-	0.00	0.00	0.00	-	0.00	-	-	-
Zoomlion	0.24	0.63	0.67	0.01	0.01	0.00	0.00	0.07	0.00	0.00	0.00	0.00	-	-	0.00	0.00	0.00	-	0.00	-	-	-
BYD	0.01	0.00	0.00	0.88	0.16	0.09	0.01	0.19	0.05	0.11	0.01	0.15	-	-	0.04	0.04	0.10	-	0.08	-	-	-
Dongfeng	0.04	0.04	0.02	0.14	0.39	0.16	0.10	0.34	0.01	0.06	0.04	0.07	-	-	0.00	0.00	0.00	-	0.01	-	-	-
FAW	0.03	0.00	0.00	0.18	0.47	0.46	0.00	0.41	0.01	0.01	0.14	0.04	-	-	0.00	0.00	0.00	-	0.00	-	-	-
Geely	0.00	0.00	0.00	0.18	0.40	0.05	0.05	0.48	0.01	0.02	0.02	0.01	-	-	0.02	0.02	0.04	-	0.03	-	-	-
SAIC	0.01	0.00	0.00	0.30	0.40	0.06	0.08	0.21	0.01	0.02	0.01	0.03	-	-	0.05	0.05	0.06	-	0.05	-	-	-
Haier	0.00	0.00	0.00	0.02	0.02	0.01	0.00	0.00	0.98	0.15	0.01	0.07	-	-	0.04	0.05	0.07	-	0.06	-	-	-
Hisense	0.00	0.00	0.00	0.08	0.12	0.01	0.00	0.01	0.25	0.87	0.01	0.81	-	-	0.24	0.25	0.37	-	0.38	-	-	-
Midea	0.01	0.00	0.00	0.02	0.00	0.04	0.00	0.02	0.26	0.06	0.13	0.01	-	-	0.03	0.03	0.03	-	0.04	-	-	-
TCL	0.00	0.00	0.00	0.10	0.10	0.01	0.00	0.05	0.16	0.80	0.01	0.82	-	-	0.39	0.40	0.39	-	0.47	-	-	-
Oppo	0.00	0.00	0.00	0.05	0.03	0.00	0.00	0.04	0.10	0.27	0.00	0.40	-	-	0.30	0.32	0.52	-	0.32	-	-	-
Vivo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Huawei	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.05	0.19	0.00	0.23	-	-	0.86	0.85	0.64	-	0.79	-	-	-
ZTE	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.05	0.19	0.00	0.22	-	-	0.81	0.81	0.60	-	0.75	-	-	-
Alibaba	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.07	0.10	0.00	0.05	-	-	0.63	0.62	0.99	-	0.88	-	-	-
Baidu	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.08	0.08	0.00	0.05	-	-	0.33	0.34	0.88	-	0.63	-	-	-
Tencent	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.08	0.21	0.00	0.15	-	-	0.73	0.71	0.99	-	0.95	-	-	-
Megvii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SenseTime	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yitu	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(b) 2015

New Applications \ Previous Applications	Sany	XCMG	Zoomlion	BYD	Dongfeng	FAW	Geely	SAIC	Haier	Hisense	Midea	TCL	Oppo	Vivo	Huawei	ZTE	Alibaba	Baidu	Tencent	Megvii	SenseTime	Yitu
Sany	0.90	0.48	0.43	0.05	0.24	0.14	0.17	0.17	0.01	0.01	0.03	0.01	0.01	-	0.01	0.01	0.01	0.01	0.01	-	-	-
XCMG	0.51	0.91	0.84	0.04	0.21	0.07	0.11	0.10	0.00	0.01	0.01	0.01	0.01	-	0.00	0.00	0.01	0.02	0.01	-	-	-
Zoomlion	0.58	0.90	0.92	0.03	0.21	0.09	0.08	0.10	0.01	0.01	0.02	0.01	0.01	-	0.01	0.01	0.02	0.01	0.02	-	-	-
BYD	0.05	0.10	0.03	0.80	0.30	0.38	0.42	0.50	0.06	0.23	0.06	0.27	0.30	-	0.10	0.10	0.29	0.35	0.26	-	-	-
Dongfeng	0.11	0.29	0.14	0.33	0.68	0.47	0.74	0.60	0.03	0.07	0.05	0.07	0.08	-	0.02	0.02	0.09	0.11	0.07	-	-	-
FAW	0.08	0.09	0.03	0.40	0.45	0.99	0.27	0.51	0.01	0.03	0.04	0.04	0.03	-	0.03	0.02	0.04	0.04	0.04	-	-	-
Geely	0.06	0.19	0.07	0.25	0.54	0.32	0.86	0.53	0.02	0.05	0.03	0.05	0.05	-	0.03	0.03	0.06	0.07	0.06	-	-	-
SAIC	0.10	0.19	0.10	0.31	0.60	0.44	0.72	0.73	0.04	0.10	0.06	0.10	0.13	-	0.06	0.06	0.13	0.16	0.12	-	-	-
Haier	0.03	0.00	0.01	0.02	0.02	0.02	0.01	0.02	0.97	0.18	0.32	0.08	0.04	-	0.09	0.09	0.09	0.06	0.09	-	-	-
Hisense	0.04	0.00	0.00	0.19	0.08	0.04	0.03	0.07	0.26	0.91	0.26	0.81	0.64	-	0.32	0.33	0.52	0.58	0.53	-	-	-
Midea	0.03	0.00	0.01	0.03	0.02	0.03	0.02	0.03	0.37	0.19	0.93	0.05	0.02	-	0.04	0.04	0.04	0.03	0.04	-	-	-
TCL	0.03	0.00	0.00	0.27	0.05	0.03	0.03	0.06	0.10	0.58	0.07	0.68	0.51	-	0.22	0.23	0.40	0.46	0.39	-	-	-
Oppo	0.01	0.00	0.00	0.17	0.04	0.04	0.03	0.08	0.10	0.62	0.02	0.70	0.75	-	0.32	0.34	0.67	0.81	0.61	-	-	-
Vivo	0.01	0.00	0.00	0.22	0.04	0.06	0.03	0.09	0.10	0.61	0.03	0.67	0.76	-	0.22	0.23	0.63	0.79	0.55	-	-	-
Huawei	0.03	0.00	0.00	0.08	0.01	0.03	0.03	0.05	0.06	0.35	0.03	0.41	0.31	-	0.86	0.90	0.70	0.54	0.76	-	-	-
ZTE	0.03	0.00	0.00	0.08	0.01	0.03	0.03	0.05	0.06	0.35	0.03	0.42	0.29	-	0.87	0.91	0.67	0.51	0.74	-	-	-
Alibaba	0.02	0.00	0.00	0.10	0.00	0.04	0.03	0.06	0.08	0.36	0.03	0.37	0.65	-	0.49	0.47	0.97	0.98	0.89	-	-	-
Baidu	0.01	0.00	0.00	0.11	0.01	0.04	0.03	0.07	0.08	0.36	0.03	0.35	0.72	-	0.33	0.32	0.88	0.99	0.76	-	-	-
Tencent	0.02	0.00	0.00	0.11	0.01	0.04	0.04	0.06	0.08	0.42	0.03	0.44	0.63	-	0.57	0.55	0.98	0.95	0.93	-	-	-
Megvii	0.00	0.00	0.00	0.05	0.02	0.01	0.01	0.01	0.03	0.23	0.00	0.18	0.15	-	0.07	0.07	0.15	0.17	0.17	-	-	-
SenseTime	0.00	0.00	0.00	0.03	0.01	0.00	0.01	0.00	0.01	0.08	0.00	0.04	0.05	-	0.01	0.02	0.06	0.07	0.06	-	-	-
Yitu	0.00	0.00	0.00	0.04	0.01	0.00	0.01	0.01	0.02	0.21	0.00	0.13	0.10	-	0.02	0.03	0.09	0.11	0.09	-	-	-

(c) 2020

New Applications \ Previous Applications	Sany	XCMG	Zoomlion	BYD	Dongfeng	FAW	Geely	SAIC	Haier	Hisense	Midea	TCL	Oppo	Vivo	Huawei	ZTE	Alibaba	Baidu	Tencent	Megvii	SenseTime	Yitu
Sany	0.62	0.51	0.39	0.12	0.29	0.13	0.23	0.26	0.02	0.07	0.02	0.06	0.08	0.08	0.04	0.04	0.08	0.08	0.07	0.09	0.08	0.08
XCMG	0.58	0.86	0.75	0.10	0.30	0.10	0.21	0.23	0.01	0.04	0.01	0.04	0.05	0.05	0.03	0.03	0.07	0.06	0.06	0.03	0.02	0.02
Zoomlion	0.54	0.96	0.93	0.08	0.20	0.07	0.11	0.15	0.03	0.07	0.01	0.07	0.10	0.10	0.06	0.05	0.12	0.12	0.11	0.07	0.06	0.05
BYD	0.10	0.09	0.08	0.81	0.50	0.36	0.46	0.55	0.03	0.17	0.03	0.16	0.19	0.22	0.15	0.14	0.20	0.19	0.20	0.10	0.07	0.09
Dongfeng	0.21	0.17	0.17	0.53	0.88	0.55	0.82	0.90	0.03	0.18	0.04	0.16	0.24	0.24	0.12	0.11	0.26	0.27	0.24	0.09	0.07	0.09
FAW	0.16	0.12	0.13	0.54	0.68	0.47	0.66	0.87	0.05	0.32	0.04	0.27	0.44	0.44	0.23	0.21	0.49	0.51	0.46	0.18	0.12	0.15
Geely	0.13	0.11	0.09	0.48	0.65	0.31	0.74	0.83	0.03	0.16	0.03	0.13	0.19	0.19	0.15	0.15	0.21	0.20	0.20	0.11	0.08	0.13
SAIC	0.19	0.16	0.16	0.50	0.77	0.41	0.77	0.92	0.04	0.24	0.04	0.20	0.30	0.30	0.20	0.19	0.34	0.34	0.33	0.15	0.11	0.15
Haier	0.01	0.00	0.01	0.03	0.03	0.02	0.02	0.03	0.95	0.24	0.60	0.06	0.04	0.04	0.04	0.03	0.05	0.05	0.05	0.02	0.01	0.02
Hisense	0.02	0.01	0.01	0.23	0.09	0.04	0.06	0.12	0.52	0.87	0.56	0.56	0.64	0.63	0.37	0.36	0.53	0.55	0.54	0.24	0.13	0.21
Midea	0.02	0.00	0.01	0.04	0.05	0.03	0.03	0.05	0.43	0.30	0.96	0.08	0.04	0.03	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01
TCL	0.02	0.01	0.01	0.37	0.08	0.04	0.05	0.11	0.15	0.67	0.15	0.90	0.58	0.59	0.36	0.35	0.47	0.49	0.48	0.17	0.08	0.12
Oppo	0.02	0.01	0.01	0.27	0.08	0.04	0.06	0.14	0.08	0.70	0.03	0.62	0.91	0.86	0.66	0.66	0.66	0.69	0.67	0.29	0.18	0.21
Vivo	0.01	0.01	0.01	0.26	0.08	0.03	0.06	0.14	0.08	0.70	0.03	0.60	0.93	0.88	0.68	0.68	0.75	0.78	0.75	0.22	0.11	0.16
Huawei	0.02	0.01	0.01	0.17	0.05	0.03	0.05	0.11	0.09	0.49	0.04	0.39	0.59	0.49	0.96	0.96	0.63	0.54	0.69	0.15	0.07	0.09
ZTE	0.02	0.01	0.01	0.15	0.05	0.03	0.04	0.10	0.09	0.46	0.04	0.37	0.56	0.46	0.96	0.97	0.61	0.51	0.68	0.14	0.06	0.09
Alibaba	0.01	0.01	0.02	0.23	0.09	0.04	0.07	0.14	0.07	0.55	0.03	0.46	0.78	0.76	0.47	0.44	0.95	0.93	0.89	0.27	0.17	0.20
Baidu	0.02	0.02	0.02	0.26	0.11	0.04	0.09	0.17	0.06	0.56	0.03	0.47	0.81	0.80	0.38	0.35	0.91	0.96	0.85	0.42	0.32	0.34
Tencent	0.01	0.01	0.02	0.25	0.09	0.04	0.07	0.15	0.08	0.66	0.03	0.52	0.83	0.81	0.52	0.49	0.95	0.94	0.93	0.36	0.24	0.27
Megvii	0.01	0.01	0.01	0.12	0.05	0.02	0.03	0.07	0.03	0.31	0.01	0.24	0.34	0.32	0.17	0.17	0.37	0.36	0.36	0.97	0.94	0.83
SenseTime	0.00	0.01	0.01	0.12	0.04	0.01	0.03	0.06	0.02	0.29	0.01	0.22	0.31	0.31	0.11	0.11	0.31	0.32	0.30	0.91	0.87	0.74
Yitu	0.01	0.01	0.01	0.17	0.06	0.02	0.04	0.09	0.04	0.41	0.02	0.33	0.52	0.52	0.20	0.19	0.53	0.58	0.51	0.77	0.71	0.62

Source: Author's calculation based on CNIPR.

First, within the same industry, firms maintain each firm's unique technology position based on the movement of (3) deepening, even though the technological distance between and within industries narrows, as shown in Subsection 3.1. Most values of s_t^{AA} are greater than those of s_t^{AB} in the same industry, and many are progressively larger (Table 4 above). Therefore, the similarity within the same industry has increased, and the characteristics of each firm have also been strengthened simultaneously. A strong differentiation can be seen in BYD in the automotive industry. That firm, a major battery manufacturer, entered the automotive industry in the 2000s, producing many electric vehicles. Thus, although BYD has accumulated automotive-related technologies and other automotive firms have amassed battery-related technologies, the disparities between them remain significant. Although such a large difference is uncommon, the technological distance between firms persists in many industries due to differences in business backgrounds and product lineups.

Thus, firms within the same industry remain differentiated, but firms have moved closer to each other based on the movement of (1) commonization, except for the home appliance industry. In many industries, the values of s_t^{AB} are relatively large, and they are gradually increasing (Table 4 above). Furthermore, not only is one value of a pair of firms greater than the other, but also both values are essentially greater. Therefore, the technological fields of firms in the same industry have overlapped even more, leading to increased technological specialization by industry. Meanwhile, in the home appliance industry, Haier, and Midea have specialized in white goods, whereas Hisense, and TCL have specialized in black goods, though Hisense sells more white goods than TCL. Consequently, firms with similar product lines are filing patents in technological fields that are similar to each other.

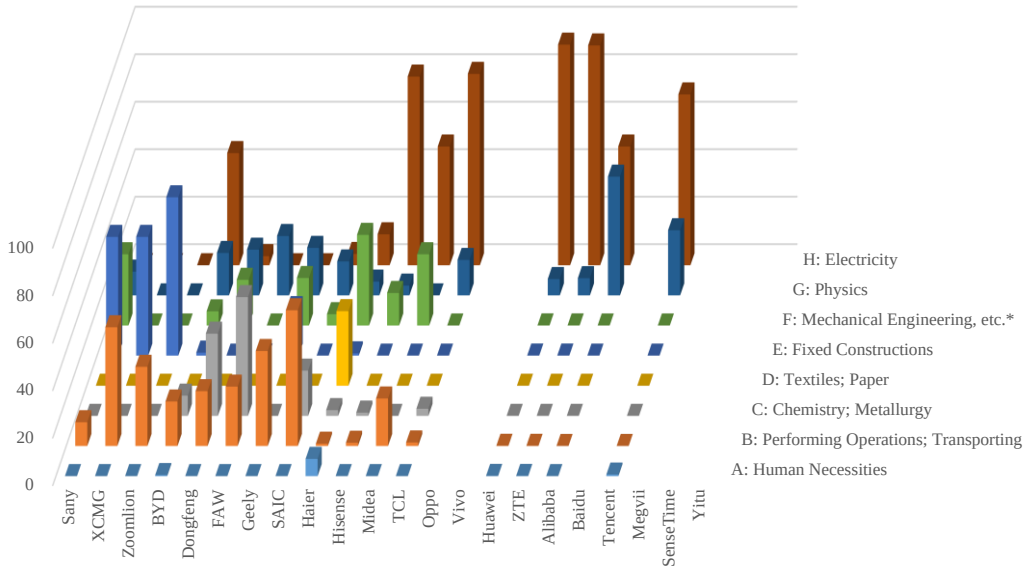
Subsequently, many industries have become technologically closer, whereas the technological distance between telecommunications equipment firms and Internet services firms has grown slightly. Although differences exist among firms, even within the same industry, the following major trends can be observed.

First, the construction equipment firms have moved technologically closer to the automotive firms based on the movement of (2) transformation. The value of $s_t^{AB^*}$ between construction equipment firms and automotive firms is gradually increasing (Table 4 above). Although many of their technologies are specific to construction equipment, they have also been applied to automobile-related "B: Performing

operations; Transporting" and "F: Mechanical Engineering; Lighting; Heating; Weapons; Blasting" (Figure 1).[4] Consequently, their core technology is directly related to construction work, but they also strive to improve product quality by accumulating diverse technologies.

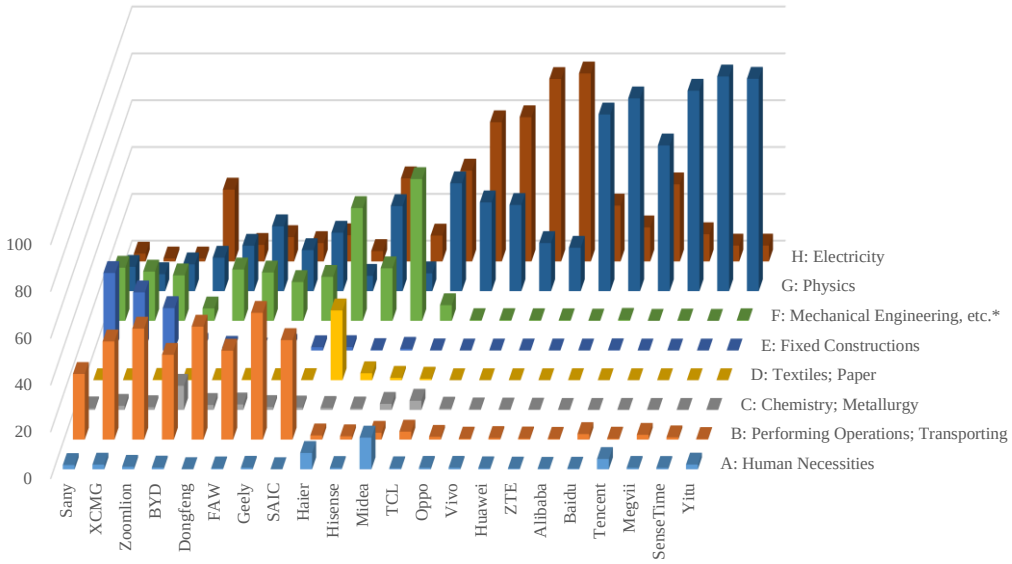
Figure 1: Proportion of each firm's technology field, 2005 and 2020 (%)

(a) 2005



[4] Dongfeng and FAW also applied to a variety of technological fields, and the decrease in the proportion of "C: Chemistry; Metallurgy" also affected the decrease in technological distance.

(b) 2020



Note: * The full description is "F: Mechanical Engineering; Lighting; Heating; Weapons; Blasting."

Source: Author's calculation based on CNIPR.

Second, except for construction equipment firms, firms have become more technologically close because they have applied more in the fields of "G: Physics" and/or "H: Electricity" based on the movement of (2) transformation. In particular, the automotive firms have moved technologically closer to home appliance (black goods), smartphone, telecommunications equipment, Internet services, and AI firms. Meanwhile, home appliance (black goods) has moved closer to smartphone, telecommunications equipment, Internet services, and AI firms (Table 4 above). Technologies in the "G: Physics" category are mostly found in the Internet services and AI industries, whereas those in the "H: Electricity" category are mostly found in the black goods, smartphone, and telecommunications equipment industries (Figure 1 above). Against the backdrop of the Fourth Industrial Revolution, many industries have expanded ICT-related technologies in addition to the technological fields specific to each industry.

Third, the technological distance between the telecommunications equipment industry and the Internet services industry has widened slightly as a result of the opposite movement seen in (2) transformation. The telecommunications equipment industry has a higher proportion of applications that are technologically close to the Internet services industry. However, the Internet services industry has a slightly lower proportion of applications that are technologically close to the telecommunications

equipment industry (Figure 1 above). Although many industries have seen an increase in applications in “G: Physics” and “H: Electricity,” the telecommunications equipment and Internet services industries, which are mostly in “G: Physics” and “H: Electricity,” have established their own specialties between the two fields (Figure 1 above). However, as the number of application fields viewed at the subclass level has increased, all firms in both industries have developed technologies in a wide range of technological fields.

4. Conclusion

This study has shown that Chinese firms are deepening and diversifying their technological fields, both within and across industries. First, the results of Similarity 1 show an increase in technological specialization by industry and a slight increase in fusion in some industries. Next, the results of Similarity 2 show that firms’ technology positions strengthen their own uniqueness and become close, particularly within industries. In other words, firms accumulate technologies while balancing the two directions of deepening and diversification.

Therefore, the technological competitiveness is determined by a combination of technologies that the firm has developed over time, rather than by a single field. A business or product is typically made up of multiple technologies, and the core technologies that define the business or product are supported by numerous peripheral technologies that increase the product’s sophistication. In other words, firms accumulate many complementary technologies around a few core technologies. As a result, although the quantity and quality of technologies are critical, understanding the characteristics of technologies as a technological structure or system that differs from one firm to another is also crucial. Moreover, as a policy implication, it must be recognized that if the government is to support firms’ R&D investment, it will be a long-term commitment until the firms are able to systematically accumulate their technologies for their products and businesses.

However, this study has only demonstrated the methods and some patterns that show the technological distance between firms in some Chinese industries. Therefore, future research should collect more case studies from various countries and industries. Furthermore, if the combination is the key to technological competitiveness, then combinations that may, or may not add value to a product or business should also be investigated. Therefore, future research should also explore the relationship between

technological structure and performance metrics, such as productivity, and profitability.

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