INNOVATION DIFFUSING IN THE DIGITAL ERA: THE IMPACT OF DIGITAL TRANSFORMATION ON ENTERPRISE KNOWLEDGE SPILLOVER

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1. Background

Innovation-driven Development is a Globally Recognized Strategic Choice.

- Insufficient R&D resources, including difficulties in human capital, research funding, and other aspects during independent innovation.
- Technological bottlenecks or innovation barriers, making it difficult to break through the current technological level.
- Innovation isolation and information asymmetry, where independent innovation lacks external feedback and fails to grasp market demand, technological trends, and policy changes adequately.
- Risks and uncertainties, where independent innovation faces risks such as investment failure or the inability to achieve expected outcomes in technological R&D.

1. Background

In the innovation process, enterprises hope to **acquire external technology**, management experience, or market information **to improve their R&D efficiency and innovation capabilities**. Alternatively, by absorbing advanced external knowledge, they aim to **avoid redundant work** in R&D, accelerate the innovation cycle, and drive technological progress.

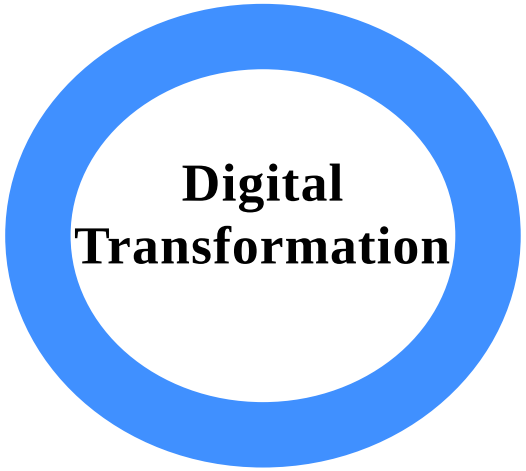
Knowledge spillover refers to the dissemination and sharing of technological and innovative knowledge between enterprises, industries, or even countries through means such as communication, cooperation, or imitation. Knowledge spillovers can provide external resource support for enterprise innovation, reduce innovation risks, accelerate technological progress, and enable collaborative innovation at the regional or industry level.

1. Background

Traditional Innovation

- quality of information transfer
- the effectiveness of information sharing
- the distance of information transmission
- .....

They have disadvantages such as linear diffusion, limited scope, lower quality, and higher time costs. The spillover is often accompanied by information transmission loss and lower transfer efficiency.



Digital Era

- altered the carriers of information in knowledge spillover
- changed the channels through which knowledge is disseminated
- transformed the interaction models between innovation entities.
- .....

Digital technologies provide new possibilities for the effectiveness of knowledge spillover, potentially reducing information transmission losses and improving the timeliness of information transfer.

2. Research questions

Objective 1	Investigating whether digital transformation of enterprises can expand the knowledge spillover of enterprises.
Objective 2	Whether this knowledge spillover is accompanied by an expansion in geographic scope.
Objective 3	This impact is influenced by heterogeneity in macroeconomic environment, industry differences, and enterprise characteristics.
Objective 4	What is the mechanism through which digitalization promotes enterprise knowledge spillovers?

Model design

The regression equation for this study is defined as follows::

$$lncited_{it} = \alpha_0 + \alpha_1 Digital_{it} + \alpha_2 Controls_{it} + \delta_i + year_t + \varepsilon_{it}$$

$$lndis_{it} = \beta_0 + \beta_1 Digital_{it} + \beta_2 Controls_{it} + \delta_i + year_t + \varepsilon_{it}$$

Where, $lncited_{it}$represents the quality of knowledge spillover for enterprise i in year t, $lndis_{it}$ denotes the distance of corporate knowledge spillover for enterprise i in year t. $Digital_{it}$represents the level of enterprise digital transformation, $Controls_{it}$ refers to a series of control variables. $year_t$is the year dummy variable. ε_{it} is the random error term.

3. Methods and Data

We use patent citation data to characterize effective knowledge spillovers between firms. If patent X from firm A is cited by patent Z from firm B, we consider that firm A has an effective knowledge spillover to firm B. We conduct textual analysis on the patent application documents provided by the CNIPA for listed companies, extracting citation information for the invention patents authorized by each company to form patent citation data pairs, Using patent titles, abstracts, IPC codes, and other information in the "China Patent Database" match patent data.

Dependent Variable	The Quality of corporate knowledge spillover (lncited)	The total annual citations, excluding self-citations, are calculated to represent the knowledge spillover quality of listed companies.
	Scope of enterprise knowledge spillover (lndis)	Utilizing the Baidu Maps API, we obtain office address coordinates for both patent applicant companies and patent citing companies. The geographical distances between each pair of citing companies are then calculated.
Independent Variable	Digital transformation of enterprises (Digital)	Count the frequency of words or phrases related to digitalization appearing in the "Management Discussion and Analysis" section of the annual reports of listed companies.

4. Preliminary results

Table 1 Baseline regression results.

	(1) lncited	(2) lncited	(3) lncited	(4) lndis	(5) lndis	(6) lndis
Digital	0.2870*** (0.0123)	0.3043*** (0.0094)	0.2671*** (0.0123)	0.0503*** (0.0114)	0.0958*** (0.0086)	0.0438*** (0.0118)
Control variable	—	Control	Control	—	Control	Control
Constant	2.8110*** (0.0211)	2.3688*** (0.0437)	2.2680*** (0.0436)	6.1700*** (0.0196)	5.9550*** (0.0398)	6.0357*** (0.0420)
Year FE	Yes	No	Yes	Yes	No	Yes
Industry FE	Yes	No	Yes	Yes	No	Yes
N	11,287	10,098	10,095	11,287	10,098	10,095
F	541.4505	285.8347	280.8313	19.3037	39.6326	23.1566
R^2	0.1938	0.1453	0.2693	0.0526	0.0230	0.0661

Note: *, **, *** denote significance levels at 10 %, 5 % and 1 % respectively. Standard errors are presented in parentheses.

The regression results show that the estimated coefficients for the impact of enterprise digital transformation on both the quality of knowledge spillovers and the geographic scope of spillovers are significantly positive in all models. This indicates that digital transformation not only significantly improves the quality of enterprise knowledge spillovers but also effectively expands their geographic scope, which is consistent with the expected outcome.

4. Preliminary results

Table 2 Robustness test.

	(1) lncited	(2) lndis	(3) lncited	(4) lndis	(5) lncited	(6) lndis
Digital	—	—	—	—	0.0776***	0.0390**
					(0.0084)	(0.0179)
L.Digital	—	—	0.2579***	0.0326***	—	—
			(0.0134)	(0.0124)		
Dige	0.0031***	0.0005**	—	—	—	—
	(0.0002)	(0.0002)				
Control variable	Control	Control	Control	Control	Control	Control
Constant	2.4959***	6.0717***	2.3456***	6.1089***	2.9534***	6.2354***
	(0.0423)	(0.0401)	(0.0490)	(0.0454)	(0.0337)	(0.0717)
Year FE	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES
Enterprise FE	NO	NO	NO	NO	YES	YES
Province FE	NO	NO	NO	NO	YES	YES
N	10,091	10,091	7,906	7,906	9,803	9,803
F	223.3391	21.7148	219.8739	15.4987	26.7481	1.8691
R^2	0.2470	0.0653	0.2750	0.0752	0.9051	0.3920

Note: *, **, *** denote significance levels at 10 %, 5 % and 1 % respectively. Standard errors are presented in parentheses.

Robustness checks were conducted by replacing the measurement of explanatory variables, applying a one-period lag to variables other than the explanatory variables, and further controlling for omitted variable issues. The conclusions remained largely unchanged, indicating that the findings of this study are robust.

4. Preliminary results

Table 3 Innovation Environment, Digital Transformation, and Knowledge Spillover.

	(1) High-Quality Innovation Environment lncited	(2) Low-Quality Innovation Environment lncited	(3) High-Quality Innovation Environment lndis	(4) Low-Quality Innovation Environment lndis
Digital	0.2745***	0.1291***	0.0606***	0.0021
	(0.0136)	(0.0253)	(0.0130)	(0.0296)
Control variable	Control	Control	Control	Control
Constant	2.2610***	2.2921***	6.0047***	6.0910***
	(0.0498)	(0.0779)	(0.0476)	(0.0914)
Fisher combination test	-0.1454***		-0.0585***	
Year FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
N	7851	2237	7851	2237
F	257.9483	115.3327	15.5869	6.7622
R^2	0.2976	0.3902	0.0663	0.0928

Regardless of the quality of the regional innovation environment, digital transformation can always expand the dissemination of a company's innovative outcomes based on its original development foundation. However, in regions with a better innovation environment, this effect is more pronounced.

4. Preliminary results

Table 4 Digital Transformation, and the Heterogeneity of Knowledge Spillovers.

	(1) Digital industries lncited	(2) Non-Digital Industries lncited	(3) Digital industries lndis	(4) Non-Digital Industries lndis
Digital	0.2522***	0.2068***	0.0656***	0.0140
	(0.0152)	(0.0180)	(0.0149)	(0.0190)
Control variable	Control	Control	Control	Control
Constant	2.3434***	2.4223***	6.1760***	5.8762***
	(0.0602)	(0.0578)	(0.0591)	(0.0611)
Fisher combination test	-0.0454***		-0.0516***	
Year FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
N	4619	5476	4619	5476
F	443.3566	102.6033	13.8867	13.3807
R^2	0.4268	0.2619	0.0535	0.0769

In both digital and non-digital industries, digital transformation significantly improves the quality of enterprise knowledge spillovers. However, the impact on firms in non-digital industries is lower than that on firms in digital industries. Furthermore, digital transformation does not significantly promote the expansion of the geographic scope of knowledge spillovers in non-digital industry firms.

4. Preliminary results

Table 5 Enterprise Digital Transformation and the Expansion of Enterprise Knowledge Dissemination Networks.

	(1) breadth	(2) breadth	(3) depth	(4) depth	(1) Speed	(2) Speed
Digital	3.4354***	3.1110***	-0.0210	-0.0577	-0.1393***	-0.0290***
	(0.3375)	(0.4687)	(0.0282)	(0.0395)	(0.0052)	(0.0053)
Control variable	Control	Control	Control	Control	Control	Control
Constant	-2.4874	-4.7301***	1.5447***	1.5070***	0.9775***	0.8218***
	(1.5620)	(1.6661)	(0.1307)	(0.1403)	(0.0246)	(0.0192)
Year FE	NO	YES	YES	YES	NO	YES
Industry FE	NO	YES	YES	YES	NO	YES
N	1[illegible]	10316	10319	10316	6680	6678
F		30.0190	[illegible]4	1.6982	134.225[illegible]	7.7894
		0.042[illegible]			[illegible]	

[illegible]tively

Digital transformation has increased the nodes of knowledge spillovers, helping firms establish a broader knowledge spillover network. This has facilitated the transition of the enterprise knowledge spillover model from a linear spillover to a network-based spillover.

Digital transformation does not have a significant impact on the depth of knowledge spillovers. This may be because, as the range of knowledge sources available to firms expands, enterprises are motivated to reduce their reliance on a single knowledge source in order to enhance the diversity of their knowledge base.

Digital transformation has shortened the average duration of enterprise knowledge spillovers, indicating that digital transformation enhances the speed of knowledge spillovers and accelerates the knowledge spillover cycle.

4. Preliminary results

Table 6 Digital Transformation of Enterprises and Inter-industry Innovation Diffusion.

	(1) Diff_ind	(2) Diff_ind	(3) Same_ind	(4) Same_ind
Digital	10.1487***	11.4182***	18.6450***	20.4473***
	(1.1767)	(1.6408)	(2.2281)	(2.8899)
Control variable	Control	Control	Control	Control
Constant	-23.2795***	-34.2982***	-26.3272**	-40.0771***
	(5.4466)	(5.8332)	(10.3130)	(10.2738)
Year FE	NO	YES	NO	YES
Industry FE	NO	YES	NO	YES
N	10098	10095	10098	10095
F	20.7545	22.2317	26.5206	25.1874
R^2	0.0122	0.0271	0.0155	0.1611

Digital transformation not only promotes knowledge spillovers within the same industry but also effectively enhances cross-industry knowledge spillovers. This suggests that digital transformation optimizes the structure of enterprise knowledge spillovers, expands the dissemination of technological innovation and knowledge spillovers among firms within the same industry, increases the accessibility of research outcomes from different industries for R&D personnel, and improves cross-disciplinary knowledge dissemination.

5. Conclusions

We used data from listed companies between 2006 and 2022, combined with information from annual reports, patent data, and the Baidu Maps API, to characterize the level of digital transformation, the quality of knowledge spillovers, and the geographic scope of knowledge spillovers of the listed companies during the sample period. Using a panel model, we identified the impact of digital transformation on the quality and geographic scope of knowledge spillovers, and examined whether digital transformation helps enterprises achieve knowledge spillovers that cross organizational and geographic boundaries.

The research results validate the hypotheses proposed in the theoretical analysis, suggesting that digital transformation can promote the diffusion of knowledge by enriching the paths and speed of knowledge dissemination, fostering cross-boundary integration of innovative outcomes, improving the structure of knowledge spillovers between firms, and subsequently expanding the geographic scope of knowledge spillovers.

The conclusions provide empirical support for leveraging the opportunity of digital transformation to promote cross-regional collaboration in technological and industrial innovation, integrate regional innovation resources, and accelerate inter-regional technological exchange and knowledge sharing.

Thank you

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