The Virtuous Cycle between Digital Technology, Enterprise Digital Transformation and Digital Economy Development -- A Study of the Dynamic Relationship Based on the PVAR Model

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Abstract: Digital transformation of enterprises is not only a choice to comply with the economic development trend, but also the use of digital technology to reduce costs and increase efficiency is a necessary path for enterprise development. Under the TOE framework, this paper takes digital technology, enterprise digital transformation and digital economy development level as the main variables. By constructing a PVAR model to incorporate the three into the same analytical framework, the dynamic interrelationship and the degree of influence between the three in the time series are empirically examined. The research results show that (1) digital technology, digital transformation of enterprises and the level of digital economy development are causally related to each other and have a mutually reinforcing influence. (2) There are inertia development and self-reinforcement mechanisms among the three variables. (3) Although the interaction among the three variables gradually decreases and tends to zero over time, it still has a strong lag. The research results enrich the dynamic relationship between digital technology, enterprise digital transformation and digital economy development, and provide strategic references for enterprise transformation and upgrading.

1. Introduction

The digital economy, as a high-level embodiment of information development, has gradually become the focus of innovation and development in various countries. The digital transformation of enterprises is not only a choice to comply with the economic development trend, but also a necessary way to reduce costs and increase efficiency. Studies have found that the impact of digital transformation on enterprises is two-sided. On the one hand, digital transformation will help enterprises to shape their resilience to withstand the uncertain risks brought by rapid market changes [1], and this strategic orientation can cushion the losses experienced by enterprises in the short term [2]; on the other hand, the development of the digital economy can also bring negative impacts such as increased competition among enterprises and rising cost pressure [3-4]. The MIT Center for Information Systems Research has found that only about 28% of enterprises have successfully achieved digitalization through a study tracking the digitization of enterprises for more than 20 years. Therefore, how enterprises achieve digital transformation has gradually become a hot issue for research. Based on theoretical bases such as innovation diffusion theory and institutional theory, scholars have explored the factors influencing the digital transformation of enterprises from the perspectives of internal and external, technical and non-technical, and driving and hindering [4], and found that IT technology [5-6], organizational culture [7], organizational structure, organizational inertia [8], executive mindset [9], and competitive market environment have had a significant impact.

Although many factors have been found to influence the digital transformation of enterprises, most studies have focused on analyzing the unique "net effect" of individual factors on digital transformation. Zhang, Xin and Xu, Yaoyu [10] pointed out that the success of digital transformation in SMEs is not driven by a single factor, but is the result of the joint interaction of multiple factors in different dimensions [11]. In fact, some scholars have started to classify each influencing factor based on the TOE framework and adopt the groupthink and fsQCA methods to explore the groupthink effect of the influencing factors of SME digital transformation [12], but the empirical research method of the effect of the joint drive of multiple factors has yet to be expanded. In view of this, in order to explore the interactions among the influencing factors more comprehensively, this paper uses the TOE framework (technology- organization-environment) based on existing studies and constructs a PVAR model to explore the dynamic relationships among the factors in the three dimensions of a time series. The results of this study can enrich the research related to the field of digital transformation, help deepen the knowledge related to the digital transformation of enterprises, and provide strategic guidance and practical insight for enterprise managers to develop a matching digital transformation route based on their own scenarios.

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2. Literature review

The TOE model provides a good theoretical perspective for studying activities such as corporate innovation. It argues that the adoption of an emerging service or technology by an organization is influenced by a combination of technical, organizational, and environmental factors, and thus can be used to explain and analyze the factors influencing the adoption and implementation of innovation by firms. The technology factor refers to the characteristic attributes inherent to the technology, such as innovation capability, relative advantage, security concerns, and perceived benefits; the organizational factor involves the characteristics and resources of the organization, including hierarchy, size, structure, business type, and capabilities; and the environmental factor represents the external attributes of the environment, such as government regulations, market environment, consumers, competitors, and other stakeholders. As a theoretical framework covering the three dimensions, the TOE framework can freely change the factors within the framework according to the different research objects, which is highly universal. With the rapid development of digital transformation and the extensive penetration of digital technologies, the business management system and competitive environment of enterprises have become increasingly complex, and the interdependence of technological, organizational and environmental factors jointly determine the innovation capability and business performance of enterprises. Therefore, some scholars have started to use the TOE framework to analyze the digital transformation research of enterprises with good explanatory power [10].

Early studies have recognized technology as one of the main factors driving organizational change in enterprises [13], and digital transformation by enterprises is seen as a change initiative. Technological innovation is the underlying support for the digital transformation of enterprises. Numerous scholars have analyzed the innovation-driven effects of digital transformation at the theoretical level, which are mainly manifested as follows: the application of digital technology innovation promotes the enhancement of automation, improves business processes and saves costs, helps enterprises achieve complementary innovation networks, promotes the exchange and sharing of digital knowledge and technology [14], and stimulates the spirit of innovation in enterprises; strengthens the ability of enterprises to integrate internal and external information and the sensitivity to forward-looking technology It strengthens the ability to integrate internal and external information and the sensitivity to forward-looking technologies, minimizes innovation risks [15], and thus promotes the digital transformation of enterprises. In order to support the continuity and sustainability of digital transformation, enterprises need to continuously carry out technological innovation and renovate and upgrade hardware facilities.

As a new financial business model, digital finance uses emerging information technologies such as big data, cloud computing and artificial intelligence to break the limits of traditional financial services, expand the scope of financial services, and reduce the information asymmetry between financial institutions and enterprises. Moreover, digital finance can more widely absorb the financial resources in the market and transform them into effective supply [16]. Then, for the digital transformation of enterprises, digital finance provides the environmental conditions for enterprises in the region to promote each other and develop together, which is beneficial to the digital transformation path of enterprises in the region. This symbiotic relationship between enterprises can promote the development of opportunities for the digital transformation of enterprises, and the development of opportunities will further expand and strengthen the symbiotic relationship between enterprises and participating subjects [17], thus reaching a virtuous circle. Therefore, the digital financial environment in a firm's region has a strong role in helping its digital transformation. The environment has a catalytic effect on the technological innovation of enterprises. For example, the construction of smart cities helps to promote the application of digital technologies in the manufacturing sector, which significantly improves the digital transformation of enterprises [18]. Not only that, according to Hicks [19], technological innovation activities cannot be separated from strong financial drivers, and digital transformation, as a higher level of technological innovation, has a more prominent demand for high-quality financial supply. Referring to the Digital Financial Inclusion Index of Peking University, the coverage breadth, depth and digitalization index of digital financial inclusion are compiled from different dimensions. The combined indexes reflect the strengths and weaknesses of the digital financial environment based on payments, insurance, monetary funds, credit services, investment, and credit in each region. This shows that the digital financial environment in each region can create a high-quality digital transformation atmosphere for local enterprises while providing support in terms of economic policies. These conditions can alleviate the financial pressure on enterprises in carrying out technological innovation, and help enterprises' digital transformation.

3. Study design

3.1. Sample selection

This paper selects Chinese A-share listed enterprises in Shanghai and Shenzhen from 2015 to 2020 as the research sample to empirically examine three factors that influence the digital transformation of enterprises. The data are obtained from the CSMAR database, information disclosure of Shenzhen Stock Exchange, the "Peking University Digital Financial Inclusion Index" issued by the Peking University Digital Finance Research Center, the Central People's Government and the website of the Ministry of Industry and Information Technology. On this basis, the preliminary sample was processed as follows: (1) to eliminate the samples of ST, *ST, S and other companies in irregular trading status; (2) to eliminate the samples that were specially treated; (3) to delete the samples with missing data, and finally 1770 sample enterprises were obtained. Considering the impact of

outliers on data analysis, the 1% quantile tailing process was performed.

3.2.Variable selection

In order to examine the relationship between technology, organization and environment of enterprises, three variables, namely digital technology, degree of digital transformation and regional digital financial environment, are used as explanatory variables of the model in this paper. A fixed-effects regression analysis is first conducted on panel data, and then a PVAR model of panel data is used to analyze the causal relationship and the degree of influence as well as the lagged effect between the variables. The definitions of variables and descriptive statistics are shown in Table 1.

Table 1. Definition of variables and results of descriptive statistics

Variable	Metrics	Definition	Avg	Std.
TEC	Innovative capabilities [20]. Digital technology acquisition capabilities [21]. Innovation-driven [22]. Technological innovation inputs [23]	The natural logarith-m of the number of patents + 1. Product develop-ment expendit-ure/main business revenue. The total number of patent applications/ num-ber of employe-d persons. The natural logarithm of corporate R&D expenditures + 1. R&D expenditure to total assets; take the average value	7.02e-08	0.876
ORG	Degree of digital transformation	Annual report digital transformation related word frequency	1.94e-06	315.521
ENV	Digital Financial Inclusion Index	Digital Inclusive Finance Index" by Peking University	-1.77e-06	58.026

4. Empirical model and analysis of results

4.1. Smoothness test

In order to prevent pseudo-regression of the test results, model building first requires that all variables are smooth, so before regressing the data, the smoothness of the data of each variable must be tested, and if the variable series is not smooth, the estimation results of the model may be biased. In this study, the LLC test, IPS test and ADF unit root test were used to test the unit root of each of the three variables. The original series of digital technology level (TEC), digital transformation degree (ORG), and regional digital financial level (ENV) were shown to be unsteady in some variables under individual test methods, and after first-order difference, they were all in a steady state, at which time the data could be The unit root test results are shown in Table 2.

Table 2. The results of the stability test

Detecting variables	LLC		IPS		ADF	
TEC	-1014.72***	√	-58.18***	√	6562.31***	√
TEC first-order differential	-447.15***	√	-129.778***	√	7581.72***	√
ORG	-61.811***	√	14.539	×	1963.85	×
ORG first-order differential	-181.199***	√	-26.449***	√	3704.87**	√
ENV	-109.36***	√	0.821	×	3519.89	×
ENV first-order differential	-1148.9***	√	-813.113***	×	27372.8***	√

Note: (1) *, **, *** are significant at the 10%, 5%, and 1% levels, respectively; (2) the original hypothesis is that the data are not smooth.

4.2. Panel data estimation results

4.2.1. Basic regression equation

$$TEC_{it} = a_0 + a_1 ORG_{it} + a_2 ENV_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

$$ORG_{it} = a_0 + a_1 TEC_{it} + a_2 ENV_{it} + \mu_i + \varepsilon_{it} \quad (2)$$

$$ENV_{it} = a_0 + a_1 TEC_{it} + a_2 ORG_{it} + \mu_i + \varepsilon_{it} \quad (3)$$

4.2.2. Analysis of regression results

The three formulas were estimated separately, and the original hypothesis of random effects was rejected at 1% significance level by the Hausman test, indicating that the fixed-effects model was the best choice for all three models. Therefore, all three models are estimated using the fixed-effects model, and the estimation results are shown in Table 3. From the regression results, it can be analyzed that the degree of digital transformation of enterprises (ρ=0.0001, $p<0.01$) and the level of regional digital finance (ρ=0.0023, $p<0.01$) can positively affect

the level of digital technology of enterprises; the level of digital technology of enterprises (ρ=12.348, p<0.01) and the level of regional digital finance (ρ= 1.813, p<0.01) can positively influence the degree of digital transformation of the firm; similarly, the digital technology of the firm (ρ=13.357, p<0.01) and the degree of digital transformation (ρ=0.094, p<0.01) can positively influence the level of digital finance in the region.

Table 3. Regression results

Variable	Description	Fixed effects (1)	Fixed effects (2)	Fixed effects (3)
Cons_	Constants	2.811 *** (0.000)	-201.506 *** (0.000)	219.099 *** (0.000)
TEC	Digital Technology Level		12.348 *** (0.001)	13.357 *** (0.000)
ORG	Degree of digital transformation	0.0001 *** (0.001)		0.094 *** (0.000)
ENV	Regional Digital Finance Level	0.0023 *** (0.0000)	1.813 *** (0.000)	
Hausman test	Test Value and Significance	Chi2 (2) = 106.79 (0.0000)	Chi2 (2) = 155.85 (0.0000)	Chi2(2) = 750.62 (0.0000)
R2	Goodness of fit	0.0442	0.182	0.206
Obs	Number of observed variables	10620	10620	10620

Note: (1) *, **, *** are significant at the 10%, 5%, and 1% levels, respectively; (2) p-values are in parentheses. Same as the following table.

4.3. Granger causality test

Since six years of data were collected, Granger causality tests were conducted with a maximum of five lags in this paper, and the results are shown in Table 4. Two-by-two Granger causality tests are conducted for the level of digital technology, the degree of digital transformation and the level of digital finance, respectively, and the results are compared for lags 1-4. It can be seen that the test results from lag 3 begin to level off and all the results reject the original hypothesis. That is, the level of digital technology of enterprises and the degree of digital transformation are mutually causal, and the level of digital technology and the level of regional digital finance are mutually causal; the degree of digital transformation of enterprises and the level of digital finance are mutually causal and can be analyzed in the next step.

Table 4. Results of Granger's causality test

Equation	Lag Period	Obs	p-value	Results
TEC does not Granger Cause ORG	1	8850	6.E-06	Rejection
TEC does not Granger Cause ORG	2	7080	0.0059	Rejection
TEC does not Granger Cause ORG	3	5310	0.0093	Rejection
TEC does not Granger Cause ORG	4	3540	0.0044	Rejection
TEC does not Granger Cause ENV	1	8850	0.4071	Acceptance
TEC does not Granger Cause ENV	2	7080	0.2056	Acceptance
TEC does not Granger Cause ENV	3	5310	9.E-05	Rejection
TEC does not Granger Cause ENV	4	3540	0.0019	Rejection
ORG does not Granger Cause TEC	1	8850	1.E-12	Rejection
ORG does not Granger Cause TEC	2	7080	2.E-17	Rejection
ORG does not Granger Cause TEC	3	5310	5.E-17	Rejection
ORG does not Granger Cause TEC	4	3540	0.0039	Rejection
ORG does not Granger Cause ENV	1	8850	5.E-22	Rejection
ORG does not Granger Cause ENV	2	7080	3.E-45	Rejection
ORG does not Granger Cause ENV	3	5310	0.0910	Rejection
ORG does not Granger Cause ENV	4	3540	0.0014	Rejection
ENV does not Granger Cause TEC	1	8850	2.E-09	Rejection
ENV does not Granger Cause TEC	2	7080	8.E-13	Rejection
ENV does not Granger Cause TEC	3	5310	3.E-09	Rejection
ENV does not Granger Cause TEC	4	3540	0.0049	Rejection
ENV does not Granger Cause ORG	1	8850	0.0000	Rejection
ENV does not Granger Cause ORG	2	7080	0.0000	Rejection
ENV does not Granger Cause ORG	3	5310	0.0000	Rejection
ENV does not Granger Cause ORG	4	3540	1.E-300	Rejection

4.4. Impulse response and variance decomposition

4.4.1. System stability discriminations

Before the PVAR impulse response and variance decomposition, the stability of the model should be tested to discern the overall stability of the model. The stability results are shown in Figure 1, in which all the characteristic roots of the three variables are less than 1 and lie within the unit circle, indicating that the model is stable, at this time, the impulse response and variance decomposition can be continued. And the lag order should be determined. In the lag order selection, according to the AIC criterion, the optimal lag order is determined to be 2 after several attempts, thus the regression equation of the three variables can be expressed as:

$$Y_{it} = a_1 Y_{it-1} + a_2 Y_{it-2} + \varepsilon_{it} + \alpha_i + \beta_t \quad i = 1,\ldots 1770; t = 1,\ldots 6 \tag{4}$$

In equation (4), Yit={TEC, ORG, ENV} is a vector containing three dependent variables, and the PVAR model introduces an individual effect αi compared to the VAR model.

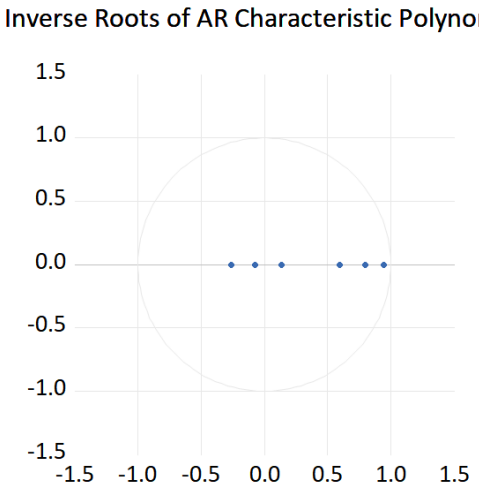

Figure 1. PVAR system stability discriminant diagram

4.4.2. Pulse analysis

Impulse response analysis is conducted for the three variables, and Figure 2 shows the impulse response results for the level of digital technology (TEC), the degree of digital transformation (ORG) and the level of digital finance (ENV). The impulse response results shown indicate that the driving effect of the level of digital technology on itself is mainly reflected in the decreasing positive effect generated in lags 1-4, and gradually decreases and returns to a plateau from period 5 onward. The degree of digital transformation shows a significant positive effect on the digital technology level of enterprises in the first two periods, which gradually decreases and levels off in the lag periods. The regional level of digital finance has a less significant impact on the level of digital technology but still shows a positive impact in the first two periods subsequently weakening and leveling off. The level of digital transformation drives itself as a diminishing positive driver and remains a positive effect after leveling off. The driving effect of digital technology on the level of digital transformation of enterprises has a change process, firstly, it shows a gradually increasing positive impact in periods 1-4, and finally, it is a gradually decreasing positive impact finally leveling off. The impact of the digital financial environment on the level of digital transformation of enterprises is more complex, lagging the first 11 periods produced a negative effect, but the negative effect gradually weakened, to the 12th period showed a positive impact and gradually return to smooth and effective. This may be due to the fact that the regional digital finance level increases after the enterprise can not respond in the short term, and the degree of digital transformation of enterprises does not immediately respond, so the first few periods produced a negative shock and subsequently changed to a positive shock. The digital financial environment has a positive shock effect on itself and decreases slowly from period to period. The impact of digital technology on the digital financial environment is concentrated in the first two periods of the lag, which is an increasing and then decreasing positive impact effect that soon plateaus. The degree of digital transformation of enterprises on the level of digital finance is an increasing and then decreasing negative shock in the first three periods, and starts to produce an increasing positive shock after the third period, which then tends to level off as a positive shock.

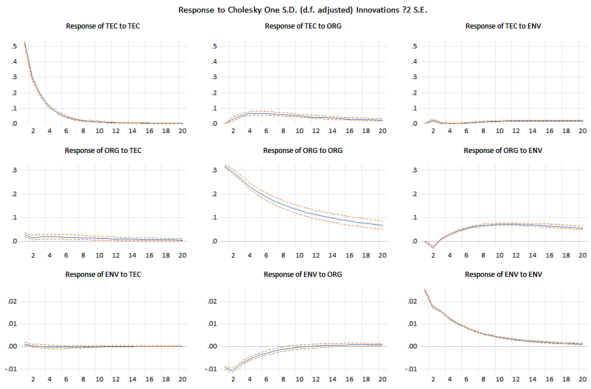

Figure 2. Impulse response diagram of digital technology level, digital transformation degree and digital finance level

4.4.3. Variance test

After the impulse responses, the variance decomposition of the three variables was carried out to explore the source and the degree of influence on each variable in the lagged period, and the results of the variance decomposition of the three variables can be seen in Table 5-7. Table 5 shows that the change in digital technology level has 98.6% influence on its own change from period 1, and the proportion of its own effect gradually decreases as time grows. The influence of the degree of digital transformation of enterprises and the level of digital finance of the region on the level of digital technology is gradually growing from period 1 to period 10, and the influence of period 10 reaches to reach 9.19% and 0.54% respectively. The results of ANOVA for the level of digital

transformation in Table 6 show that from period 1, the factors affecting the level of digital transformation are mainly their own changes reaching 88.19%, compared to the digital financial environment which is less sensitive to changes in the level of digital transformation reaching 11.81%. In the next 10 years, the impact of the level of digital technology on the degree of digital transformation and the impact of the degree of digital transformation on itself gradually increase, with 0.03% and 92.24% respectively by the 10th year. The change in the level of digital finance has a decreasing effect on the change in the degree of digital transformation, reaching 7.72% in the 10th period. Table 7 shows the variance decomposition table of the level of digital finance, which shows that the level of digital finance has a greater impact on its own changes and lasts longer, and does not significantly decrease in 10 years until the tenth year still has 98.69% impact. The impact of changes in the level of digital technology and the degree of digital transformation on the level of the digital economy is relatively weak but also increasing year by year, and the impact in the 10th period also reaches 0.16% and 1.15% respectively.

Table 5. Variance decomposition table for digital technology level (TEC)

Response variable		Impulse variable		
Variables	Period	TEC	ORG	ENV
TEC	1	98.62985	1.201401	0.168749
TEC	2	97.56028	2.168093	0.271624
TEC	3	96.58424	3.149742	0.266019
TEC	4	95.37715	4.298361	0.324493
TEC	5	94.19579	5.394953	0.409255
TEC	6	93.12522	6.398719	0.476062
TEC	7	92.20030	7.283283	0.516412
TEC	8	91.41388	8.051697	0.534419
TEC	9	90.74678	8.714540	0.538682
TEC	10	90.17772	9.285515	0.536770

Table 6. Variance decomposition table of the degree of digital transformation (ORG)

Response variable		Impulse variable		
Variables	Period	TEC	ORG	ENV
ORG	1	0.000000	88.18904	11.81096
ORG	2	0.041980	85.28152	14.67650
ORG	3	0.039398	86.68139	13.27921
ORG	4	0.035796	88.10208	11.86213
ORG	5	0.033133	89.35616	10.61070
ORG	6	0.031719	90.34101	9.627268
ORG	7	0.031352	91.08065	8.887993
ORG	8	0.031874	91.61614	8.351983
ORG	9	0.033114	91.99093	7.975959
ORG	10	0.034899	92.24321	7.721890

Table 7. Variance decomposition table for the digital financial environment (ENV)

Response variable		Impulse variable		
Variables	Period	TEC	ORG	ENV
ENV	1	0.000000	0.000000	100.0000
ENV	2	0.004030	1.280733	98.71524
ENV	3	0.021852	1.262029	98.71612
ENV	4	0.051354	1.214890	98.73376
ENV	5	0.080275	1.145822	98.77390
ENV	6	0.105174	1.097492	98.79733
ENV	7	0.124775	1.076214	98.79901
ENV	8	0.139544	1.081057	98.77940
ENV	9	0.150367	1.108100	98.74153
ENV	10	0.158175	1.152418	98.68941

5. Conclusions

First, digital technology, enterprise digital transformation and the development level of regional digital economy are mutually causal. The three variables form a virtuous circle of mutual reinforcement. Second, the three variables have inertial development and self-reinforcing mechanism. For example, the improvement of enterprise digital technology will actively promote the development of later enterprise digital technology.Third, to explore the source and degree of influence of each variable in the lagging period, organizational factors, that is, the degree of digital transformation of enterprises, all have a certain weight.

It can be seen that even though the technical factors, organizational factors and environmental factors are a virtuous circle, the most important and leading role in it is the degree of digital transformation of enterprises. From the perspective of digital technology, in order to improve the level of digital technology, we must first encourage the digital transformation of enterprises and help them to transform digitally so that they can drive the development of technology. Similarly, in order to develop the digital economy and build a digital China, it is not enough to rely only on the government and individual leading enterprises to drive. Digital industrialization is the starting point, and the digitalization of industry is the goal. Only when a large number of enterprises undergo digital transformation can we create a general environment for the high-quality development of the digital economy.

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