Digital Transformation, Optimization of Supply Chain Resilience and Total Factor Productivity in Manufacturing

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Abstract. This paper uses the data of A-share listed manufacturing enterprises in Shanghai and Shenzhen stock markets from 2010 to 2020 to study the effect of digital transformation on the total factor productivity of enterprises. The results show that digital transformation improves the total factor productivity of enterprises.Moreover,digital transformation optimizes dynamic capabilities from the perspectives of supply chain proactive ability, supply chain reactive ability, and comprehensive supply chain design quality ability, and enhances the total factor productivity of the manufacturing industry through four aspects,namely alleviating financing constraints, reducing asset specificity, improving the level of specialized division of labor, and promoting innovation synergy.Digital transformation has a greater effect on the total factor productivity of state-owned enterprises, non-high-tech enterprises, labor-intensive enterprises. The research conclusions provide factual support and policy implications for promoting digital transformation to assist in the high-quality development of enterprises.

Keywords: Digital Transformation, Manufacturing Industry, Total Factor Productivity of Enterprises.

1 Introduction

A new round of scientific and technological revolution and industrial transformation is developing rapidly. The complexity of the external environment for industrial development has increased significantly, and the internal factors and conditions have changed repeatedly. Digital transformation is not only a key stage for micro enterprises to follow the law of development in the new era, but also the actual needs of enterprises in the face of market competition, and an inevitable choice to respond to national policies and conform to the development of the Times. Manufacturing enterprises play an irreplaceable role in driving China's economic development and improving the trade advantage index. As one of the important fields for the application of digital

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achievements, manufacturing enterprises' digital transformation mechanism regarding total factor productivity is worthy of in - depth consideration.

The economic consequences and influencing mechanisms of digitalization have been the main focus of previous studies, but no unified conclusion has been reached. The economic consequences of digitalization can be summarized from macro and micro perspectives. From a macro perspective, the development of the digital industry improves the efficiency of digital reform and promotes the improvement of total factor productivity[1]. From a micro perspective, digital transformation can significantly improve the total factor productivity of enterprises, but it may be manifested in two relationships, namely "U - shaped" relationship and "inverted U - shaped" relationship. Specifically, the "U - shaped" relationship is manifested as a pattern where the use of digital factors and productivity show a decreasing - first - then - increasing trend[2]. The "inverted U" relationship is manifested as a pattern where the use of digital technology and productivity show an increasing - first - then - decreasing trend. The reason is that excessive investment in digitalization increases management costs while reducing production costs of enterprises, resulting in resource waste and labor mismatch. There is also a view that digital transformation cannot positively promote productivity improvement[3], that is, there is a "digital paradox". Moreover, this situation varies according to different factors such as industry and enterprise size [4]. However, there are few literatures on the impact of digital transformation on total factor productivity from the perspective of supply chain resilience optimization. Digital transformation affects the docking, coordination and resource integration of upstream and downstream enterprises through correlation effects, thus affecting the total factor productivity of enterprises. How to enhance the degree of enterprise correlation on the chain and improve and optimize the resilience of the supply chain is an important direction to solve the phenomenon of "islanding" and "fragmentation". Based on this, this paper will further explore the role of digital transformation in improving enterprise total factor productivity from the perspective of supply chain resilience optimization through theoretical analysis and empirical research.

2 Literature Overview and Research Hypothesis

2.1 Digital Transformation and Total Factor Productivity of Enterprises

Digital transformation drives the traditional manufacturing industry to realize the upgrading of industrial structure and the modernization of the economic system, thereby leading enterprises towards the future. First, digital technology connects the originally dispersed enterprises and markets, realizes the linkage development of all links of the industrial chain and supply chain, improves the level of interconnection, and then improves the innovation efficiency of enterprises, promotes the agglomeration of innovation factors, expands the innovation space of enterprises [5], and enhances the resilience to cope with risks and shocks. Node enterprises use big data technology to accurately analyze the data of industries, enterprises and consumers, and provide timely and abundant mass data for innovation. At the same time, they reduce the input of traditional production factors, promote the integration of production factors and

emerging technologies, accelerate the deep integration of digital technologies and products and services, so as to generate disruptive innovative products and improve the total factor productivity of enterprises. Second, the combination of digital transformation and operation management, and the effective use of data assets, greatly promote the transformation and upgrading of enterprises and the construction of sustainable competitive advantages, enhance flexibility and toughness, promote enterprises to build an industrial development ecology, and form the driving force for continuous high-quality development of enterprises. Third, digital transformation can smooth the cycle of data elements, eliminate the information barriers between industries and enterprises, effectively alleviate the negative effects of resource waste and information islands in upstream and downstream industries, and reduce transaction costs, and promote cooperation between enterprises, and form economies of scale, and strengthen the capacity of the industrial chain and value chain. On the basis of the above analysis, this paper proposes research hypothesis 1: Digital transformation improves enterprise total factor productivity.

2.2 Digital Transformation, Supply Chain Resilience Optimization and Enterprise Total Factor Productivity

Supply chain resilience can be understood as the integration of supply chain initiative, supply chain response and supply chain design quality, and the integration of key resources [6-7]. Among them, supply chain initiative focuses on the ability of the industry to warn and defend against changes in the face of external risks and challenges. Enterprises in the supply chain should not only passively adapt to market changes and demands, but also actively explore market opportunities, innovative technologies and products, finance innovative behaviors, and improve the technical level and competitiveness of the entire supply chain. In other words, the supply chain initiative drives innovation coordination, alleviates financing constraints, and promotes the improvement of total factor productivity of enterprises. Supply chain responsiveness emphasizes rapid response and recovery from the risk of disruption of the industrial chain and supply chain. Through rapid response to market demand, reducing inventory costs, optimizing production processes, strengthening risk management, and promoting information sharing and collaboration, it drives professional division of labor, reduces asset specialization, and promotes the improvement of total factor productivity of enterprises. The comprehensive capability of supply chain design quality can be expressed as the ability of correlation and transformation between node enterprises, driving innovation collaboration, reducing asset specificity, and improving enterprise total factor productivity. Therefore, this paper further reviews how digital transformation promotes the improvement of total factor productivity of enterprises through the role of four types of key resources inherent in the three dynamic capabilities.

Ease financing constraints. Financing constraints restrict enterprises' innovation, research and the improvement of total factor productivity, while the application of digital technology makes enterprises' financing more flexible and diversified, and effectively solves the problem of short - term cash - flow deficiency[8].First, enterprises improve their information - sorting and analysis abilities through digital transfor-

mation, promote the improvement of resource - allocation efficiency, and then enhance the production efficiency of enterprises in the chain, reduce production costs, and reduce the need for external financing, thus alleviating financing constraints from within the enterprises. Second, the improvement of information availability can alleviate the information asymmetry between outside investors and enterprises, strengthen the information transparency among enterprises in the supply chain. It makes the supply chain more stable and reliable, provides a good foundation for easing financing constraints, expands the existing capital flow of enterprises, and improves asset-management efficiency and total factor productivity. Based on the above analysis, this paper puts forward research hypothesis 2: Enterprise digital transformation can improve enterprise total factor productivity by easing financing constraints.

Reduce asset exclusivity. Asset specificity is often used to measure the external transaction costs of an enterprise. The cost of asset transformation is an important consideration in digital transformation decisions. Therefore, the more specific assets an enterprise has, the higher the cost of asset conversion during digital transformation. Information dissemination caused by digital technology facilitates communication among enterprises and visualizes key elements of contracts, thereby reducing the cost of negotiation and contracting[9], curbing the degree of asset specificity, optimizing the correlation among enterprises, improving supply chain resilience and stability, and making full use of resources and technological advantages. Thus improving the production efficiency of manufacturing enterprises. Based on this, this paper proposes research hypothesis 3: Enterprise digital transformation improves enterprise total factor productivity by reducing asset specialization.

Improve the level of specialization. Digital technology promotes the expansion of market scope, improves the degree of division of labor and specialization, thereby improving the production efficiency of specific links of products, reducing the supply cost of service products, realizing the effective allocation of resources, and thus boosting overall productivity [10]. In addition, enterprises with strong resource endowments will transfer products and services of a higher technical level to those with weak resource endowments. This will greatly stimulate the enthusiasm of enterprises with weak resource endowments to learn advanced technologies and improve the autonomous and controllable ability of key nodes[11].Based on this, this paper proposes research hypothesis 4: Enterprise digital transformation improves the total factor productivity of enterprises by improving the level of specialization.

Achieve innovation synergy. Enterprise digital transformation can have a disruptive impact on the innovation process, thereby significantly improving innovation efficiency. Digital technology provides accurate market tracking tools and efficient communication tools[12], which greatly improve the technological innovation ability of enterprises, facilitate the creation of a new collaborative mode, improve the understanding of enterprises on market changes, and effectively coordinates the acquisition of various resources, identifies innovation opportunities, and even achieves large-scale, personalized customization, promotes the spillover of digital technology, reduces the dependence of enterprises on production factors, copes with external shocks more effectively and enhances resilience, thus improving the total factor productivity of enterprises[13].Based on this, this paper proposes research hypothesis 5: Enterprise

digital transformation improves enterprise total factor productivity by realizing innovation synergy.

3 Research Design

3.1 Sample Selection and Data Processing

Based on the data of manufacturing A - share listed enterprises in Shanghai and Shenzhen from 2010 to 2020, this paper carried out relevant processing. First, the enterprise data of ST, *ST and PT in the sample were excluded. Second, abnormal data and seriously missing enterprise data were eliminated. Third, the data of companies listed less than one year were excluded. Fourth, winsorization at the 1% and 99% levels was performed on each continuous variable of the data. Finally, an interpolation method was adopted to supplement part of the data, and 11,617 observations were obtained. All data are from CSMAR and corporate annual reports.

3.2 Variable Setting and Measurement

Explained variables. The explained variable was total factor productivity (TFP). The total factor productivity was calculated by the OP method. And it was tested by the LP method for robustness.

Explanatory variables. Explanatory variables are digital transformation (DTG). 76 key feature words, which fall into five categories including artificial intelligence and blockchain, in the annual reports of listed enterprises are taken as keywords for enterprise digital transformation[14]. And the natural logarithm of the sum of the total word frequency plus 1 is taken.

Control variables. Based on previous studies, the control variables selected are as follows: Return on assets (ROA), ratio of net profit to total assets; Business Age (Age), the natural logarithm after subtracting the year of observation from the year of listing; Sales revenue growth rate (XSZZ), the amount of operating revenue in the current period less the amount of operating revenue in the same period of the previous year divided by the amount of operating revenue in the same period of the previous year; Capital intensity (CS), the ratio of total assets to operating income; Tobin's Q value (Tobin), the ratio of book value to the market value of the enterprise; The degree of market competition is measured by the HHI of an individual enterprise's market share calculated from its main business income. Specific descriptive statistics are shown in Table 1.

Table 1. Descriptive statistics.

Variable	Observation	mean	min	med	max
TFP_OP	11617	6.530	5.054	6.463	8.500
DTG	11617	2.798	0.693	2.773	5.352
ROA	11617	0.042	-0.233	0.041	0.199

Age	11617	1.997	0.693	2.079	3.219
XSZZ	11617	0.163	-0.433	0.113	1.877
CS	11617	2.030	0.498	1.762	6.977
Tobin	11617	2.166	0.885	1.742	8.669
HHI	11617	0.097	0.000	0.074	0.403

3.3 Model Construction

The baseline regression model is constructed as follows:

$$TFP_{i,t} = \alpha_0 + \alpha_1 DTG_{i,t} + \alpha_2 X_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (1)$$

Among them, the explained variable TFP represents the total factor productivity of the enterprise, and the explanatory variable DTG is used to measure the digital transformation level of the manufacturing enterprise.$X_{i,t}$are a series of control variables that affect the toughness of the manufacturing industry chain in region i.

4 Empirical Test and Result Analysis

4.1 Baseline Regression

In this paper, the panel fixed effect model is used to regression the benchmark model, and the results are shown in Table 2. Digital transformation significantly improves the total factor productivity of enterprises.

Table 2. Baseline regression analysis.

	(1) TFP_OP	(2) TFP_OP	(3) TFP_OP	(4) TFP_OP
DTG	0.165***	0.078***	0.033***	0.031***
	(0.004)	(0.003)	(0.009)	(0.007)
Controls	No	Yes	No	Yes
Firm/Year	No	No	Yes	Yes
N	11617	11617	11617	11617
R^2	0.1489	0.5396	0.322	0.577

Note. *,** and *** indicate significant at the 10%, 5% and 1% levels, respectively. The standard errors of all models are clustered at the enterprise level. The same below.

4.2 Robustness Test

The results of the robustness test are presented in Table 3. First, the micro-perspective digital transformation index constructed by scholars[15] is used to conduct regression again, and the regression results are consistent with the baseline regression results.

Second, we conduct a robustness test on the total factor productivity measured by the LP method, and the regression results are robust. Then, we take the samples from 2012 to 2019 for re-regression, and the results are still robust. Finally, we carry out the endogeneity test by the systematic GMM method. The test statistics indicate that all the instrumental variables are valid. They meet the GMM usage conditions of the system, and the regression results are robust.

Table 3. Robustness test.

	(1) TFP_OP	(2) TFP_OP	(3) TFP_LP	(4) TFP_LP	(5) TFP_OP	(6) TFP_OP	(7) TFP_OP
DTG			0.052***	0.050***	0.028***	0.026***	0.010***
			(0.010)	(0.008)	(0.009)	(0.007)	(0.003)
DTG_w	0.029***	0.029***					
	(0.007)	(0.006)					
L.TFP_OP							0.748***
							(0.040)
Controls	No	Yes	No	Yes	No	Yes	
Firm/Year	Yes	Yes	Yes	Yes	Yes	Yes	
N	11617	11617	11617	11617	8969	8969	8901
R^2	0.322	0.578	0.321	0.593	0.320	0.582	
AR (1)							0.000
AR (2)							0.132
Hansen							0.404

4.3 Further Analysis: Mechanism Test

The present paper reveals the impact of digital transformation on the total factor productivity of enterprises. Theoretical analysis points out that digital transformation can improve the total factor productivity of enterprises through four aspects: easing financing constraints, reducing asset specialization, improving professional division of labor, and realizing innovation collaboration. Referring to the mechanism test method of scholars[16], this paper will carry out mechanism regression and show the main results in Table 4.

First, Financing. This section focuses on how financing impacts the relationship between digital transformation and enterprises' total factor productivity. As can be seen from column (1) in Table 4, the FC index is significantly negative. Digital transformation can alleviate financing constraints, secure funds, ensure that enterprises can obtain sufficient capital guarantee, and promote the improvement of enterprises' total factor productivity.

Second, Reduce Asset Exclusivity. Generally speaking, external transaction costs at the micro level are often measured by asset specificity. This paper measures asset specificity (ASS) using the ratio. The ratio is calculated as the sum of net fixed assets,

construction in progress, intangible assets and long - term amortized expenses divided by the total capital of the enterprise. As shown in column (2) of Table 4, digital transformation can reduce asset specificity, and relevant mechanisms exist.

Third, Improve the Level of Specialization. Enterprises use digital technology to better integrate into the market and participate in the division of labor [17]. This can reduce the coordination costs for enterprises, monitor and adjust the operational status of the supply chain, and improve the total factor productivity of enterprises by exerting economies of scale, comparative advantage effect and technology spillover effect. The specialized division of labor promotes the gradual decomposition of production links, and manufacturing enterprises increase the need for association with external nodes[18]. The result shown in column (3) of Table 4 is significantly positive, indicating that digital transformation can improve the level of specialization and verifying the rationality of the hypothesis.

Finally, Achieve Innovation Synergy. It can be seen that digital transformation itself is closely related to innovation. However, innovative R & D activities themselves are characterized by high risk, high externality, long return cycle, etc. When external uncertainty intensifies, collaborative innovation can help disperse R & D risks of digital transformation and share R & D costs, thus generating synergies and achieving economies of scale. This can improve the total factor productivity of enterprises. The innovation collaboration mechanism focuses on innovation quality. Therefore, this paper uses the total number of patent applications of the enterprise in the current year as a metric index, adds 1 to it and then takes the natural logarithm. As shown in column (4) of Table 4, PAT is significantly positive, indicating that digital transformation can improve the degree of innovation collaboration and verifying the rationality of the hypothesis.

Table 4. Mechanism test.

	(1) FC	(2) ASS	(3) VAS	(4) PAT
DTG	-0.019***	-0.005**	0.007**	0.130***
	(0.003)	(0.002)	(0.003)	(0.020)
Controls	Yes	Yes	Yes	Yes
Firm/Year	Yes	Yes	Yes	Yes
N	11617	11617	11617	11617
R^2	0.244	0.091	0.042	0.283

4.4 Heterogeneity Test

This part analyzes the heterogeneity of property rights, whether it is a high-tech enterprise or not, and the intensity of factors.

Nature of property rights. The access to key resources in response to external shocks is affected by the nature of property rights of enterprises, and enterprises with different property rights have different functions in the industrial chain and supply chain. In this paper, the sample enterprises are divided into non-state-owned enterprises and state-owned enterprises. Columns (1) and (2) of Table 5 show that the digital trans-

formation of state-owned enterprises has a more significant impact on the total factor productivity of enterprises. The reasons are that state-owned enterprises have strong technical foundation, strong chain leading force, sufficient capital, convenient policy support, strong forecasting and response ability to cope with external uncertainties, and promote the improvement of total factor productivity of enterprises.

Scientific and technological attributes. Whether an enterprise has the characteristics of "high technology" has an impact on its ability to resist risks. In this paper, the sample enterprises are divided into high-tech enterprises and non-high-tech enterprises. According to columns (3) and (4) of Table 5, it can be seen that the digital transformation of non-high-tech enterprises has a significant impact on the total factor productivity of enterprises. The reason is that high-tech enterprises have higher technology endowment, and non-high-tech enterprises have lower basic technology level, resource utilization degree and digitalization level than high-tech enterprises. The introduction of digitalization has a more prominent role in enterprise innovation, and enterprises with an obvious role in innovation can maintain production and operation more stably in the face of shocks, and enhance their ability to resist risks.

Measurement of Factor Intensity. We take the logarithm of the ratio of net fixed assets to the number of employees as the measure of enterprises' factor intensity. Samples larger than the median are capital - intensive enterprises, while samples smaller than the median are labor - intensive enterprises. As shown in columns (5) and (6) of Table 5, digital transformation significantly improves the total factor productivity of both labor - intensive and capital - intensive enterprises, but the digital transformation of labor - intensive enterprises has a more significant effect on the improvement of total factor productivity. The reason is that labor - intensive enterprises are more flexible in coping with external shocks, while the adjustment mode of capital - intensive enterprises is limited by the flexibility of asset types, which results in a partial loss of performance for capital - intensive enterprises.

Table 5. Heterogeneity test.

	(1) TFP_OP	(2) TFP_OP	(3) TFP_OP	(4) TFP_OP	(5) TFP_OP	(6) TFP_OP
DTG	0.026***	0.028**	0.0325**	0.032***	0.034***	0.026***
	(0.008)	(0.012)	(0.015)	(0.007)	(0.010)	(0.009)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm/Year	Yes	Yes	Yes	Yes	Yes	Yes
N	8158	3459	2474	9143	5173	6444
R^2	0.598	0.566	0.584	0.581	0.601	0.591

5 Conclusion

The research conclusion is that digital transformation can significantly enhance the total factor productivity of enterprises and optimize dynamic capabilities from the perspectives of proactive supply chain capabilities, supply chain response capabilities, and comprehensive supply chain design quality. It also involves key resource integra-

tion centered on alleviating financing constraints, reducing asset specificity, promoting specialized division of labor, and facilitating innovation collaboration. Additionally, digital transformation has a greater effect on improving the total factor productivity of state-owned enterprises, non-high-tech enterprises, and labor-intensive enterprises. According to the above research results, this paper puts forward the following policy recommendations. First, optimize digital transformation policies centered around supply chain resilience, and enhance the total factor productivity of enterprises according to local conditions and resilience-related characteristics. The policy should promote deep integration, solve the problems that the lack of key core links in the manufacturing supply chain leads to weak autonomy and control ability of the supply chain, and that the weak circular link ability inside and outside the supply chain leads to a low status of the supply chain network nodes. It should enhance the interactive circulation both inside and outside the supply chain, enabling the manufacturing industry to transform from the vertical correlation of the supply chain to a supply chain cluster. Ease financing constraints, reduce asset specialization, improve specialization, and promote innovation collaboration to comprehensively improve the total factor productivity of enterprises. Second, build a close - knit supply chain ecology and strengthen supply chain and manufacturing resilience. Continue to promote the digitalization of the whole process of engineering, supply, production, and operation. Make full use of digital twins, generative artificial intelligence, and other technologies and solutions, make real - time decisions and take actions based on data, further release the value of investment, respond more quickly to fluctuations and changes, and improve the level of risk - resistance. Enterprises should review and reshape supply chain networks to optimize layout without creating silos or new bottlenecks, and apply data and artificial intelligence to make them more transparent and flexible, thus building lasting resilience.

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