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The Impact of Digital Transformation on Economic Growth in the Northeast

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Abstract: *Digital transformation can drive economic growth, and improve the level of science and technology innovation to empower economic development. To investigate whether digital transformation has a sustained and stable promotion effect on the economic growth of the three northeastern provinces, based on the panel data of Liaoning, Jilin, and Heilongjiang provinces from 2011 to 2020, using the economic level as the explanatory variable, digital transformation as the explanatory variable and the level of human capital, investment in physical capital, the degree of government intervention, the level of opening up to the outside world, and the level of scientific and technological development as the control variables, and applying the methods of fixed effect model and other methods of empirical testing. The results show that: (1) digital transformation can enhance the rapid economic development of Northeast China, i.e., the higher the degree of digital transformation, the faster the economic development. (2) Human capital is an important factor affecting the economic development of the Northeast, and its fundamental, strategic, and decisive role in the economic and social development of the Northeast is increasing. (3) Physical capital investment can play a contributing role in the development of the Northeast economy, add new technology machines to enterprises, and promote technological progress in the Northeast, which can lead to both short-term stable economic development and long-term steady economic improvement. Accordingly, policy recommendations for digital transformation to promote economic growth in the Northeast are put forward in terms of strengthening digital infrastructure, cultivating digital talents, increasing scientific and technological innovation, and other aspects.*

Keywords: *digital transformation; northeastern revitalization; reform and development*

1. Introduction

With the continuous development of blockchain, cloud computing, big data, and other emerging digital technologies, the digital economy has gained momentum in recent years and has become an important engine for future economic growth. Digital transformation is the core carrier and key task for the development of the digital economy. In January 2022, the State Council issued the "14th Five-Year Plan for the Development of the Digital Economy", which points out that: with data as the key element, and with the deep integration of digital technology and the real economy as the main line, it strengthens the construction of digital infrastructure, improves the governance system of the digital economy, and collaborates to promote digital industrialization and industrial digitization, empower the transformation and upgrading of traditional industries, cultivate new industries, new business forms and new modes, continuously strengthen and optimize China's digital economy, and provide strong support for the construction of a digital China. Recently, the 20th Party Congress also proposed to accelerate the development of the digital economy and promote the deep integration of the digital economy and the real economy, to promote the realization of high-quality development of the economy and comprehensively build a modern socialist country. It can be seen that digital transformation is a new weapon to promote the rapid development of China's economy.[1]

Northeast since 2003, the implementation of the strategy to revitalize the northeast, but with the industrial transformation, brain drain, and population aging, the economic level of the northeast has had a great impact on the GDP growth rate of Heilongjiang, Jilin, and Liaoning in 2021 is only 6.1%, 6.8%,

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5.8%, the effect does not meet expectations. To truly realize the revitalization of the Northeast, so that the old industrial base follows the pace of the times, vigorously developing the digital transformation has become the new goal of the high-quality development of the Northeast economy, deepening the role of the digital economy driving the traditional economy "shift" to the digital economy, improve the core competitiveness of the Northeast economy. Therefore, in this context, the study of countermeasures for the digital development of the Northeast region has important practical value and strategic significance in helping the new round of revitalization of the Northeast. This paper selects the panel data of Liaoning, Jilin, and Heilongjiang provinces and cities from 2011 to 2020 for regression analysis, applies the entropy value method to give weight to the indicators, conducts empirical research on the impact of economic growth on the degree of digital transformation of the three provinces, analyzes the problems and puts forward suggestions for future development, and provides practical reference significance for the realization of the digital transformation of the Northeast in the comprehensive revitalization of the region. The study analyzes the problems and puts forward suggestions for future development, providing practical references for realizing digital transformation in the comprehensive revitalization of the northeast region.

2. A Review of Literature Related to Digital Transformation and Economic Growth

Since the 21st century, with the continuous development of science and technology, the fourth industrial revolution has quietly begun, and digital transformation has a very important impact on the international situation. Digital transformation is the core carrier of the development of the digital economy and the key task, the economy is also closely integrated with digital science and technology, and gradually evolved into a digital economy. Unlike the real economy, the new digital economy is based on digital technology as the core, digital intelligent information as the basis, high network level as the carrier, to explore the new road of future economic development, which is profoundly affecting the economic and social development, and has a disruptive impact. 2020 China's digital economy industry added value of 39.2 trillion yuan, the scale of the same period of GDP accounted for 38.6%, the nominal growth rate of 9.7%, higher than the nominal growth rate of GDP in the same period by 6.7 percentage points. Promoting the digital transformation of the real economy in Northeast China is an important path to realize the revitalization of Northeast China.

Many scholars validate and analyze digital transformation for economic growth from different perspectives. Shen Kunrong and Qiao Gang (2022) fully study the mechanism of digital economy for economic growth from the supply-side and demand-side perspectives, based on which, this paper also puts forward some relevant policy recommendations, such as the construction of digital infrastructure in advance, and vigorously promote the digitalization of industries.[2] Digital technology is the foundation of the digital economy, Tian Xiujuan (2022) based on the analytical framework of Schumpeter's endogenous growth theory, so that digital technology empowers the transformation and development of the real economy and promotes the development of economic quality.[3] Qi Yudong and Chu Xi (2021) analyze the demand and supply aspects, analyze the theoretical mechanism from the perspective of economic structural transformation, and elaborate on the significance of the development of digital economy affecting economic growth.[4]

In terms of industrial digitization, manufacturing digitization and enterprise digitization, Guo Kesha, Yang Tulong (2023) found that industrial digital transformation is an important way to promote stable economic growth and high-quality development, and analyzed the existence of different mechanisms and paths of digital transformation in manufacturing and service industries. [5]Zheng Xuefeng (2023) believes that China is at a critical stage of transformation of economic growth mode, and the digital transformation of manufacturing industry may create new impetus and new model for economic growth.[6] Yang Wang (2022) believes that industrial digitalization uses the borderless characteristics of data elements to help the quality change of economic development and the high-quality development of the economy, analyzes the innovation effect, synergistic effect, spillover effect and sharing effect brought about by industrial digitalization, explores its impact on the high-quality development of the economy, and summarizes the theoretical system of industrial digitalization for the promotion of common wealth.[7]

In the aspect of digital transformation on the high-quality development of economy, Jue Chen (2022) believes that digital economy is the main economic form after agricultural economy and industrial economy. It takes data resources as the key element, modern information network as the main carrier, the integrated application of information and communication technology and the digital transformation of various elements as an important driving force, and promotes a new economic form that is more unified with fairness and efficiency. We can enhance the driving force for high-quality economic development

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by improving innovation capacity in key core technologies, moving up the industrial chain, deepening the digital transformation and upgrading of the manufacturing industry, improving the governance of the digital economy, and fostering the market for data factors.[8] Zhen Junjie (2023), from the perspective of synergy theory, theoretically explored the synergistic mechanism of digital innovation and high-quality economic development, used provincial panel data to construct a dual system coupling and coordination model of "digital innovation - high-quality economic development", and empirically examined the synergistic effect and dynamic evolution of China's digital innovation and high-quality economic development. It empirically examines the synergistic effect and dynamic evolution of China's digital innovation and high-quality economic development, and provides theoretical support for the synergistic evolution of digital innovation and high-quality economic development.[9] Wang Ziyan (2023) based on the theoretical mechanism of digital economy affecting economic high-quality development, used hierarchical analysis to determine the weight of each index system, combined with entropy value method to construct the evaluation system, and carried out a comprehensive evaluation, and the result is that digital economy is an important part of improving economic high-quality development, and it provides effective support for economic high-quality development.[10] Zhang Hong (2022) based on the connotation of digital economy and the reality of development, combined with the definition of high-quality development, summarizes the connotation of high-quality development of digital economy from the five dimensions of the theoretical perspective, points out the problems of high-quality development of China's digital economy still from the practical perspective, and puts forward countermeasures from the policy perspective.[11]

3. Study design

3.1 Selection of variables

3.1.1 Explained variables

Economic growth is the dependent variable in this paper, and from the existing literature, we can find that scholars usually choose variables such as gross domestic product (GDP), average annual GDP growth rate, per capita GDP and per capita income to reflect the economic strength and growth rate of different individuals, although all these variables can reflect the level of economic growth, considering that the economic growth is not only related to the total amount of GDP but is also affected by the population size in the year. Most scholars believe that GDP per capita can remove the influence of population size and can finely measure economic growth. The explanatory variables in this paper are expressed in terms of GDP per capita.[12]

3.1.2 Explanatory variables

(1) Digital Transformation Indicator Measurement

Concerning the research of Fan Shengyue and Li Yaolong, this paper takes the level of digital infrastructure investment and the level of digital application as the level of digitalization as the first level of indicators, and the selection of specific indicators is shown in Table 1. To determine the weights of the indicators at all levels, this paper adopts the entropy method, and the data are measured with the help of the SPSSAU analytical algorithm platform. The formula of the entropy value method is as follows.

Indicator normalization.

All indicators in the text are positive and are expressed as follows.

$$Z_{ij} = \frac{x_{ij} - \min\{x_{1j}, \ldots, x_{nj}\}}{\max\{x_{1j}, \ldots, x_{nj}\} - \min\{x_{1j}, \ldots, x_{nj}\}}$$

Calculate the weighting:

$$P_{ij} = \frac{z_{ij}}{\sum_{i=1}^{n}}, i=1,\ldots,n, j=1,\ldots,m$$

Calculate the entropy value:

$$e_j = -k\sum_{i=1}^{n} p_{ij}\ln(p_{ij}), j = 1, \ldots, m$$

Where $k = 1/\ln(n) > 0$ satisfies$e_j > 0$

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Calculate the information entropy redundancy:

$$d_j = 1 - e_j, j = 1, \ldots, m$$

Calculate the weights of the indicators:

$$w_i = \frac{d_j}{\sum_{j=1}^{m} d_j}, j = 1, \ldots, m$$

Calculate the composite score:

$$s_i = \sum_{i=1}^{m} w_j x_{ij}, i = 1, \ldots, n$$

Table 1: Comprehensive evaluation index system for the degree of digital transformation

variant	Constructing indicators	Metrics	Weight (%))	forward and backward
Level of digitization	Level of digital infrastructure	Internet broadband access ports (10,000)	5.33%	+
		Local exchange capacity (10,000 doors)	11.68%	+
		Mobile telephone exchange capacity (10,000)	5.65%	+
		Cell phone base stations (10,000)	6.05%	+
		Length of fiber optic lines (km)	6.39%	+
		Internet penetration (%)	3.09%	+
		Proportion of administrative villages with Internet broadband access (%)	1.77%	+
	Level of digital applications	Mobile SMS traffic (billions of messages)	3.99%	+
		Cargo turnover (tons)	17.06%	+
		E-commerce sales (billions of dollars)	11.40%	+
		Total postal business (billions of dollars)	7.47%	+
		Total telecommunication business (billions of dollars)	11.75%	+
		Revenue from courier services ($ million)	8.37%	+

Table 2: Table of variables selection and their interpretation

Variable type	variable name	notation	Interpretation of indicators
explanatory variable	economic growth	PGDP	GDP per capita
explanatory variable	Degree of digital transformation	DIGITAL	Entropy weighting method
control variable	Level of human capital	HUMAN	Average years of schooling (years)
	Investment in physical capital	MCINV	Ratio of social fixed assets to GDP
	Level of government intervention	GOV	Fiscal expenditure as a percentage of GDP
	Egypt's open-door policy towards the outside world	OP	Ratio of total imports and exports to GDP of the location of the business unit
	Level of scientific and technological inputs	R&D	Regional expenditure on science and technology as a ratio of GDP

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(2) Other variables

In addition to the degree of digital transformation, other influencing factors need to be controlled. The control variables selected for this study mainly include: the level of human capital (HUMAN) is expressed by the average years of education of the population, the investment in physical capital (MCINV) is expressed by the per capita investment in the whole society's fixed assets, the degree of government intervention (GOV) is expressed by the share of the local fiscal expenditure in GDP, the level of openness to the outside world (OP) is expressed by the share of the total amount of imports and exports of the location of the business unit in GDP. The level of investment in science and technology (R&D) is expressed by the ratio of the expenditure on science and technology in the selected region to the GDP, and all the indicators are shown in Table 2. For the sake of data smoothness, this paper will take the logarithmic treatment of the indicators in the regression model.

3.2 Data sources

Due to the serious missing values before 2011, the sample data in this paper consists of the panel data of three provinces in China from 2011 to 2020, which are mainly obtained from the China Statistical Yearbook (2011-2020) and Heilongjiang Statistical Yearbook (2011-2020), Jilin Statistical Yearbook (2011-2020), and Liaoning Statistical Yearbook (2011-2020). Yearbook (2011-2020) and Liaoning Provincial Statistical Yearbook (2011-2020). In this paper, outliers in the data are eliminated, and for a small amount of missing data, interpolation is used.

3.3 Modeling

There are studies in the literature that show that the role of digital transformation on economic growth is mainly in the study of capital and labor on economic growth. The traditional Cobb-Douglas production function (C-D production function) is:

$$Y = AK^{\alpha}L^{\beta}e^{\delta} \tag{1}$$

Where A denotes the efficiency coefficient of production, which is usually a constant. y denotes the total output of the economy, K denotes the physical capital input, L denotes the labor input, is the random perturbation term, is the output elasticity of capital, and is the output elasticity of labor. Because of the many factors affecting economic growth, this paper adds a series of factors that may affect the economic level, such as the level of human capital, physical capital investment, the degree of government intervention, the level of openness to the outside world and the level of scientific and technological development, into the model analysis. This paper takes the natural logarithm of the C-D production function and introduces the degree of digital transformation and other control variables to explore the impact of digital transformation on economic development, and this paper constructs the following econometric model:

$$\begin{aligned} LnPGDP_{it} = c + \beta_1 LnDIGITAL_{it} + \beta_2 LnHUMAN_{it} + \beta_3 LnMCINV_{it} + \beta_4 LnGOV_{it} + \beta_5 LnOP_{it} + \\ \beta_6 LnR\&D_{it} + u_{it} + \varepsilon_i \end{aligned} \tag{2}$$

where subscript i represents the city, t represents the year, and$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ is the parameter to be estimated, andu_{it} is to represent the individual differences in the cross-sectional cells of the metric, andε_i represents the randomized disturbance term. The explanatory variable PGDP denotes economic growth and the explanatory variable DIDITAL denotes the level of digital development. The control variables HUMAN denotes the level of human capital, MCINV denotes physical capital investment, GOV denotes the level of government intervention, OP denotes the level of openness to the outside world, and R&D denotes the level of science and technology investment.

4. Empirical research

4.1 Descriptive statistics

As can be seen from Table 3, the data are relatively smooth overall.

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Table 3: Table of descriptive statistics

name (of a thing)	Sample size	minimum value	maximum values	Average	Standard deviation	
economic growth	30	40859.47	8475.189	26093	58629	Y
Degree of digital transformation	30	0.3001367	0.1979683	0.0428003	0.7405983	X1
Level of human capital	30	9.588	0.2938144	9.1	10.1	X2
Investment in physical capital	30	0.9033246	0.3174105	0.2793992	1.335302	X3
Level of government intervention	30	0.2462708	0.0595435	0.1563224	0.370932	X4
Egypt's open-door policy towards the outside world	30	0.1668448	0.0777731	0.071401	0.2995659	X5
Level of scientific and technological inputs	30	0.0124593	0.0038982	0.0076304	0.0218597	X6

Figure 1 shows the scatter plot of the degree of digital transformation on economic growth in the Northeast and combined with the trend line from the figure it can be seen that there is a certain positive correlation between the level of digital development and economic growth in the Northeast.

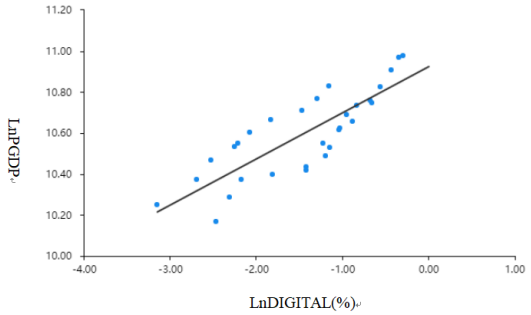

Figure 1: Scatterplot of the level of digital development on economic growth in the Northeast region

4.2 Correlation analysis

To prevent the correlation between some of the variables from being too high, which leads to the existence of multicollinearity between the variables, the correlation analysis of the variables was carried out in this paper, and the results are shown in Table 4. From the analysis results, it can be seen that there is also a high correlation between the explanatory variables and the explained variables and some of the explanatory variables.

Table 4: Correlation analysis table

	lny	lnX1	lnX2	lnX3	lnX4	lnX5	lnX6
lny	1						
lnX1	0.828***	1					
lnX2	0.871***	0.856***	1				
lnX3	0.0130	-0.276	-0.294	1			
lnX4	0.0640	0.0600	-0.170	0.481***	1		
lnX5	0.364**	0.499***	0.580***	-0.430**	-0.593***	1	
lnX6	0.672***	0.754***	0.802***	-0.303	-0.354*	0.823**	1

Note: *** represents p<0.01, ** represents p<0.05, and * represents p<0.1, indicating significant at 1 %, 5 %, and 10 % levels, respectively.

The results of the Variance Inflation Factor (VIF) test showed that the VIF value of each explanatory

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variable was less than 10, indicating that the selected explanatory variables met the requirements of the study and there was no problem of multicollinearity, as shown in Table 5.

Table 5: Variance inflation factor test

Variable	VIF	1/VIF
lnX1	6.27	0.15948
lnX2	5.12	0.195255
lnX3	1.62	0.619113
lnX4	2.81	0.356234
lnX5	4.8	0.208212
lnX6	7.24	0.138202
Mean VIF	4.64	

4.3 Stability tests

The results of the unit root test are shown in Table 6. lny, lnX2 and lnX6 two variables in the horizontal series reject the original hypothesis of the existence of a panel unit root of these variables, lny is significant at the 1% level, and lnX2, lnX6 are significant at the 5% level. lnX1, lnX3, lnX4, lnX5 four variables in the horizontal series have a unit root, and in the first-order difference test lnX3, lnX4, lnX5 are significant at 1% level, and lnX1 is significant at 1% level in the second order difference test, it can be concluded that the data in this study are smooth and can be analyzed in a valid panel regression analysis.

Table 6: ADF test

variable name	difference in order	t	p	threshold value			Test results
				1%	5%	10%	
LNY	0	-3.399**	0.011	-3.809	-3.022	-2.651	smoothly
LnX1	0	-2.028	0.274	-3.753	-2.998	-2.639	non-stationary
LnX2	0	-5.993***	0	-3.809	-3.022	-2.651	smoothly
LnX3	0	-2.351	0.156	-3.679	-2.968	-2.623	non-stationary
LnX4	0	-0.927	0.779	-3.809	-3.022	-2.651	non-stationary
LnX5	0	-1.67	0.447	-3.679	-2.968	-2.623	non-stationary
LnX6	0	-7.777***	0	-3.809	-3.022	-2.651	smoothly
ΔLnX1	1	-1.945	0.311	-3.833	-3.031	-2.656	non-stationary
ΔLnX3	1	-3.63***	0.005	-3.689	-2.972	-2.625	smoothly
ΔLnX4	1	-5.076***	0	-3.689	-2.972	-2.625	smoothly
ΔLnX5	1	-4.585***	0	-3.689	-2.972	-2.625	smoothly
ΔΔLnX1	2	-3.438***	0.01	-3.859	-3.042	-2.661	smoothly

Note: In this study, the ADF unit root test is used, Δ, ΔΔ denote first-order and second-order differences, respectively, and ***, **, and * denote the rejection of the original hypothesis that the series is not stationary at the 1%, 5%, and 10% significance levels, respectively.

4.4 Panel regression analysis

4.4.1 Panel model selection

In this study, we use a degree of digital transformation, human capital investment, physical capital investment, degree of government intervention, level of openness to the outside world, and level of scientific and technological investment as the explanatory variables, and economic growth as the explanatory variable for panel model construction.

The panel model involves three models which are mixed the POOL model, fixed effects FE model, and random effects RE model. Firstly, the model test is conducted to facilitate the identification of the optimal model, which is shown in Table 7: The F-test presents a significance at the 5% level F(2, 21)=55.816, p=0.000<0.05, implying that the FE model is better compared to the POOL model. The Hausman test statistic is negative, rejecting the original assumption of the random effects model, and the fixed effects FE model is used. Combining the above analyses, this paper finally takes the fixed effect FE model as the final result.

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Table 7: Summary of panel model results

term (in a mathematical formula)	POOL model	FE Model	RE model
intercept (the point at which a line crosses the x- or y-axis)	0.113	6.595**	0.113
	-0.041	-5.009	-0.041
LnX1	0.103*	0.199**	0.103*
	-2.073	-6.695	-2.073
LnX2	4.671**	2.026**	4.671**
	-4.139	-3.754	-4.139
LnX3	0.124**	0.066**	0.124**
	-3.124	-3.737	-3.124
LnX4	-0.064	0.062	-0.064
	(-0.578)	-0.902	(-0.578)
LnX5	-0.078	0.012	-0.078
	(-1.102)	-0.328	(-1.102)
LnX6	0.031	0.037	0.031
	-0.225	-0.628	-0.225
R^2	0.877	0.783	0.877
R^2 (within)	0.883	0.964	0.883
sample size	30	30	30
inspect	F (6,23)=27.249, p=0.000	F (6,21)=94.409,p=0.000	$\chi2(6)$=163.493,p=0.000

Note: * represents p<0.05, ** represents p<0.01, t-values in parentheses

4.4.2 Basic regression

Table 8: Panel data fixed effects regressions

VARIABLES	lnY	lnY	lnY	lnY	lnY	lnY
lnX1	0.290*** (-0.0195)	0.229*** (-0.0259)	0.214*** (-0.0192)	0.194*** (-0.0265)	0.202*** (-0.029)	0.199*** (-0.0298)
lnX2		2.173 *** (-0.7)	2.142*** (-0.512)	2.114*** (-0.511)	2.105*** (-0.517)	2.026*** (-0.54)
lnX3			0.0760*** (-0.0159)	0.0720*** (-0.0163)	0.0694*** (-0.0169)	0.0665*** (-0.0178)
lnX4				0.0696 (-0.0663)	0.0623 (-0.0679)	0.0621 (-0.0688)
lnX5					0.0223 (-0.0318)	0.0119 (-0.0363)
lnX6						0.0367 (-0.0585)
Constant	11.02*** (-0.0299)	6.018*** (-1.612)	6.081*** (-1.177)	6.215*** (-1.182)	6.277*** (-1.198)	6.595*** (-1.317)
Observations	30	30	30	30	30	30
Number of COUNTRY	3	3	3	3	3	3
R-squared	0.894	0.924	0.961	0.963	0.964	0.964

Note: *, **, and *** indicate significant at the 10%, 5%, and 1% levels, respectively; t-statistics are in parentheses.

In this study, the fixed effects FE model is used as the final result, and Model 1-Model 8 in Table 8 is the regression process of adding explanatory variables step by step, and it can be seen from Table 8: before adding the control variables, the explained variable economic growth and the explanatory variable degree of digital transformation are significant at the 1% level, and the value of the regression coefficient is 0.199>0, which indicates that the degree of digital transformation degree will have a significant positive impact on economic growth relationship. For every 1% increase in digital transformation in the Northeast, the economic level of the Northeast will increase by 0.29%.

After adding the control variables, the level of human capital, and physical capital investment is significant at the 1% level, which indicates that it will have a significant positive impact on economic growth. The level of government intervention, the level of openness to the outside world, and the level of investment in science and technology do not show significance, which indicates that these three control variables do not have a positive impact on economic growth.

According to the results in Table 8, it can be concluded that the degree of digital transformation has the greatest impact on economic growth without the influence of other variables. After the addition of

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explanatory variables, the influence of the degree of digital transformation is weakening, but the goodness of fit is improving, the overall validity of the model is increasing, and the explanation of the improvement of economic growth in Northeast China is more convincing.

With the inclusion of control variables, the level of human capital has a significant positive relationship at the 1% level. Human capital is the sum of knowledge, skills, and qualities formed by laborers in education as well as in their work. The old industrial base of Northeast China, as the leader of the reform and opening-up period, high-quality technical talents are the endogenous driving force to promote the economic development of Northeast China. In recent years, the Northeast has paid considerable attention to the cultivation of high-quality technical talents, and capital has been heavily invested in basic and higher education to establish a team of high-quality, high-end, and innovative talents.

Physical capital investment has a significant positive relationship at the 1% level. Physical capital investment is one of the most important drivers of economic growth. The Northeast region is based on heavy industry, and the government regulates the level of investment in enterprises. The old state-owned enterprises have solid technology and bring small and medium-sized form enterprises to innovate continuously, which motivates enterprises to develop and use new technology, innovate raw materials for products, expand the scale of production, increase production efficiency, and optimize the quality of products. The government should also continuously invest in enterprises to optimize new technology and equipment, replace old equipment, purchase digital machines, add new equipment, improve the technicality of equipment, and realize the intelligence of state-owned capital.

The degree of government intervention, the level of openness to the outside world, and the level of investment in science and technology do not have a significant effect on economic growth to a certain extent, which is also the direction to be worked on to improve the level of economic growth in the Northeast in the future.

The investment in science and technology reflects the local ability to emphasize technological innovation and influence the coordinated development of the ecological environment and economic growth through technological research and development, technology introduction, etc. In 2018, the proportion of the R&D expenditure of enterprises above the scale in Shenyang City to the main business income was only 1.05%, which is lower than the national average level of 1.06%. This indicates that the level of scientific and technological innovation in the Northeast is still relatively weak. This shows that the level of effective data informatization of the northeastern government is not high, the allocation of factors is unreasonable, and input of factors of production is still insufficient, and the mechanism for the transformation of scientific research achievements is still imperfect.

The degree of government intervention, the government of the Northeast region is too much intervention in the market and resource allocation, reducing the efficiency of factor allocation, which leads to the emerging science and technology-based innovative enterprises not getting a foothold in the market, the shortage of resources, lack of raw materials, and systemic constraints so that the vitality of enterprises is declining, which is not conducive to the development of the economy of the Northeast. Traditional old state-owned enterprises are highly dependent on state policies, although some enterprises have begun to carry out digital transformation, but their management systems and operating mechanisms have not yet undergone substantial digital transformation.

The level of opening to the outside world, in the Northeast, Liaoning Province has the ports of Dalian and Yingkou, and Heilongjiang Province has the China-Russia railroad and ports directly to Russia, which is the main import and export path in the Northeast. Since the beginning of the new crown epidemic in 2020, the ports and railroads have been closed one after another, raw materials can not be imported, and industrial products can not be exported, so the Northeast is trying to improve the level of opening up to the outside world is undoubtedly a heavy blow.

4.5 Robustness Tests

4.5.1 Replacement of variables

To ensure the relative accuracy of the research results, a robustness test is required. In this paper, we choose to replace the explanatory variables and add control variables to conduct the robustness test.

This paper uses the logarithmic value of regional per capita GDP to represent the level of economic growth, in order to further verify the stability of the regression results, choose to use the logarithmic value of regional GDP to replace the explanatory variables, further regression, robustness test regression

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results are shown in Table 9.

Table 9: Replacement of the explanatory variable regional GDP

VARIABLES	lnX7	lnX7	lnX7	lnX7	lnX7	lnX7
lnX1	0.217***	0.163***	0.144***	0.154***	0.167***	0.165***
	(0.0212)	(0.0297)	(0.0205)	(0.0289)	(0.0311)	(0.0320)
lnX2	9.836***	1.954**	1.915***	1.929***	1.915***	1.846***
	(0.0325)	(0.804)	(0.548)	(0.557)	(0.554)	(0.580)
lnX3		5.342***	0.0929***	0.0950***	0.0904***	0.0878***
		(1.849)	(0.0170)	(0.0178)	(0.0181)	(0.0191)
lnX4			5.419***	-0.0360	-0.0486	-0.0488
			(1.260)	(0.0723)	(0.0727)	(0.0740)
lnX5				5.350***	0.0386	0.0297
				(1.288)	(0.0341)	(0.0390)
lnX6					5.457***	0.0318
					(1.283)	(0.0629)
Constant						5.733***
						(1.415)
Observations	30	30	30	30	30	30
Number of COUNTRY	3	3	3	3	3	3
R-squared	0.802	0.840	0.929	0.930	0.933	0.934

Note: *, **, and *** indicate significant at the 10%, 5%, and 1% levels, respectively; t-statistics are in parentheses.

As can be seen from the results, the regression coefficient of the explanatory variables of Model 1 is 0.165, which is positive and significant at a 1% confidence level, proving that the impact of digital transformation on the level of the economy is positive and significant, and it also shows that the results of this paper are less affected by the special samples, and the benchmark regression results are robust and reliable.

4.5.2 Adding explanatory variables

Table 10: Addition of control variable FDI

VARIABLES	lnY	lnY	lnY	lnY	lnY	lnY
lnX1	0.290***	0.229***	0.214***	0.194***	0.202***	0.198***
	(-0.0195)	(-0.0259)	(-0.0192)	(-0.0265)	(-0.029)	(0.0300)
lnX2		2.173***	2.142***	2.114***	2.105***	2.003***
		(-0.7)	(-0.512)	(-0.511)	(-0.517)	(0.544)
lnX3			0.0760***	0.0720***	0.0694***	0.0586***
			(-0.0159)	(-0.0163)	(-0.0169)	(0.0201)
lnX4				0.0696	0.0623	0.0560
				(-0.0663)	(-0.0679)	(0.0696)
lnX5					0.0223	0.00423
					(-0.0318)	(0.0376)
lnX6						0.0383
						(0.0589)
lnX8						-0.00916
						(0.0107)
Constant	11.02***	6.018***	6.081***	6.215***	6.277***	6.676***
	(-0.0299)	(-1.612)	(-1.177)	(-1.182)	(-1.198)	(1.328)
Observations	30	30	30	30	30	30
Number of COUNTRY	3	3	3	3	3	3
R-squared	0.894	0.924	0.961	0.963	0.964	0.966

Note: *, **, and *** indicate significant at the 10%, 5%, and 1% levels, respectively; t-statistics are in parentheses.

Increase the logarithmic value of foreign trade dependence FDI as a control variable for another robustness test, foreign trade dependence is expressed as the ratio of the total amount of imports and exports to the GDP, where the total amount of imports and exports is converted to RMB according to the exchange rate between China and the United States. The results of the robustness test regression are shown in Table 10, in which the regression coefficient of the main explanatory variables is 0.198, which is positively significant at the 1% level, further indicating that the benchmark regression results of this paper are robust and reliable.

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5. Conclusions and recommendations

5.1 Conclusion

This paper examines the impact of digital transformation on the level of economic growth in the Northeast region with panel data from 2011-2020. Considering that an impact on the growth of the Northeast, this paper also adds control variables such as the level of human capital, physical capital investment, the level of government intervention, the level of opening up to the outside world, and the level of scientific and technological investment to analyze and explore their paths of action. The study shows that (1) digital transformation can enhance the rapid economic development of the Northeast, that is, the higher the degree of digital transformation, the faster the economic development. (2) Human capital is an important factor affecting the economic development of the Northeast, and its fundamental, strategic, and decisive role in the economic and social development of the Northeast is increasing. (3) Physical capital investment can play a catalytic role in the development of the Northeast economy, adding new technology machines to enterprises and promoting technological progress in the Northeast, which can lead to both short-term stable economic development and long-term steady economic improvement.

5.2 Recommendations

5.2.1 Advancing digitization

Create a favorable atmosphere for the digital economy market environment. Strengthen the digital infrastructure of the Northeast region, lay a firm foundation for transformation, and improve the efficiency of digital transformation. The government should play a guiding role, conduct in-depth research on traditional state-owned enterprises, strengthen the advantages of a complete industrial system, rationally allocate industrial layout in response to the problems of lagging development and economic downturn, and formulate corresponding digital transformation strategies to reduce the risk of transformation, improve the speed of transformation, and avoid the negative impact of digital transformation. The government should provide positive publicity for enterprises that have successfully transformed, not stopping at a momentary transformation, and continue to introduce macro policies and goals to lead. For small and medium-sized enterprises, the government should vigorously support them, and collaborate with large enterprises to innovate, integrate develop, and share information efficiently.

5.2.2 Developing digital talent

With the low birth rate, high brain drain, and accelerated aging of the population in the Northeast, the supply structure of labor factors in the Northeast has been difficult to adapt to the needs of the digital revitalization of the old industrial bases, and it has become urgent to retain high-end talents and technical talents for the Northeast.

Based on the "2020 Graduate Employment Quality Report" that has been made public by the five northeastern schools, the largest proportion of graduates from Jilin University, Northeastern University, and Dalian University of Technology is in the regional distribution of employment.[13] In cooperation with other provinces and cities with faster development of the digital economy, we have formulated special talent introduction policies to keep talents in the Northeast through incentives such as upgrading remuneration packages and providing housing subsidies and welfare benefits. Innovative enterprise digital talent management system, in the face of the serious problem of talent outflow from the northeast, enterprise talent management has also become critical. Enterprises should innovate the appraisal system of enterprise employees, actively improve the supporting facilities of digital technology, optimize the internal and external environment of the enterprise, pay attention to the integration and development between digital technology and enterprise business, use digital technology to innovate the internal governance model of the enterprise, promote the synergistic development of various departments of the enterprise so that the talents can reasonably flow in an orderly manner, and cultivate the digital economy to establish the new industry pattern of digitalization for the industrial digitalization transformation of the old industrial base.

5.2.3 Increase efforts in science, technology and innovation

The investment in science and technology innovation in the Northeast is low and the conversion rate of science and technology is not high. The main reason is that the cycle of enterprise innovation and research and development engineering is too long and technological innovation is difficult. The government should actively introduce policies to guide enterprises to carry out technological innovation and research and development projects, increase capital investment in technological innovation and

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research and development in the region, and provide strong support from the joint government and colleges and universities, to jointly promote the development of digital science and technology innovation and research and development projects. At the same time, the government should provide more convenient conditions in terms of policy and more adequate support in terms of resources for the development of productive service industries.

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