Using Stata Software to Study the Impact of Technological Innovation on Economic Growth
Based on Panel Data of 31 Provinces and Cities in China from 2007-2017

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Abstract
The impact of technological innovation on economic growth is undeniable, but exactly how it affects China's economic growth still needs to be studied in depth. This paper will collect and collate panel data from 31 provinces and cities in China from 2007-2017, using both input and output aspects of technological innovation, and conduct a regression analysis of the linear relationship between the variables separately using a fixed-effects model. The conclusions drawn indicate that, firstly, capital input and labour input are still responsible for promoting economic growth; secondly, innovation can contribute to economic growth to a certain extent. However, there is still a need to continue to promote the technological innovation system. By region, as there are differences in the development of different regions in China, how to better develop regional economies still needs to be adapted to local conditions.

Keywords-*economic growth; technological innovation; econometric analysis.*

1. INTRODUCTION

The advent of the Internet era has brought new opportunities and challenges for economic development, creating more new models of economic development. The theory of economic growth, which states that technological innovation is the source of economic growth, is well known in today's society. 2021 is the opening year of China's 14th Five-Year Plan and a new journey to build a comprehensive socialist modern state, where China is leading the world in economic growth. The innovation-driven development strategy is being effectively implemented and the innovation environment is being optimised. This paper is introduced by the innovation theory of Schumpeter, the "father of innovationist economics", who defined innovation as the introduction of a new combination of factors and conditions of production into a production system that had never existed before. The most important of these is innovation, and it is the innovation that leads to economic growth and development. In modern economic development, economic growth is susceptible to fluctuations due to a variety of factors, including human and capital resources, while technological innovation has a more pronounced impact on economic growth.

The use of computer technology is reflected in all aspects of our lives. For example, the use of Java's IBM Domino technology for banking transactions to complete the conversion of online and offline money transfers; the use of Python technology's PyCharm tool to write web crawlers for legitimate data collection and acquisition; and the use of Stata software for data regression analysis and modelling operations, thus making it easier and faster to draw economic trends and corresponding conclusions. This enables a quicker and more accurate understanding of the extent to which various factors influence economic growth and how they relate to each other.

In this paper, data regression analysis is carried out empirically through Stata software, where the data are strongly balanced. Combined with Romer's endogenous economic growth theory, the Cobb-Douglas production function is applied in a new way, with different indicators selected as explanatory variables, explanatory variables and other control variables. Three regression sub-models were obtained for each of China's 31 provinces and cities by region, and regression analysis was conducted on the total sample and sub-samples using a fixed-effects model. Thus, confirming that technological innovation has a contributory effect on economic growth, particularly in

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regions with high levels of economic development. However, when studying regional development, one cannot ignore the fact that there are differences between regions, which is why the development of the middle and western regions needs to draw on the eastern regions.

In the progress of the study, due to space limitations, many issues are only preliminarily addressed, especially the lagging effect of technological innovation on economic growth, which has not been analysed in depth. However, the role of technological innovation on economic growth can give good insights to the government and enterprises, and this paper also analyses the factors that promote economic growth by region, which is of certain significance for the better implementation of policies and subsequent research by local conditions.

2. Materials and Methods

2.1. Literature Review

There have been many studies of economic growth models both at home and abroad, but the conclusions reached by these studies over the years have not been entirely consistent, suggesting that the issue of economic growth models deserves further discussion.

First, at the level of technological innovation on economic growth. Wu Xuan (2017) studied the relationship between patents and economic growth in China from 1996 to 2015, and his results indicate that original technology represented by invention patents plays an important role in the process of transforming China's economic growth [12]. Song Jie (2019) studied the relationship between technological innovation and economic growth in Shandong province and concluded that there is a long-term equilibrium relationship between technological innovation inputs and outputs and economic growth, both of which can contribute to economic growth. At the same time, technological innovation inputs can promote technological innovation outputs and thus indirectly contribute to economic growth [10]. He Xingbang (2019) empirically examines the impact of technological innovation on economic growth based on inter-provincial panel data from 2000-2014, showing that technological innovation can generally improve the quality of China's overall economic growth, but on the other hand, technological innovation can also increase the inequality of income distribution and widen the gap between rich and poor [6].

Yang Kaijun and Min Chongzhi (2019) established a system of economic growth quality indicators to empirically analyse data from the Guangdong-Hong Kong-Macao Greater Bay Area from 2007-2017, and the results affirm the role of technological innovation for economic growth and the fact that the role of technological innovation for economic growth shows a stronger effect in regions with high levels of economic growth quality [15]. However, taking East China as an example, Xu Hongjin and Qi Meng (2021) measured the contribution of technological innovation to economic growth in East China from 2009 to 2018. They concluded that the stock of physical capital was the main factor of economic growth in East China, while the contribution of technological innovation to economic growth was low and volatile [14].

Secondly, the paper also considers other controls such as the degree of government intervention, the degree of openness of the economy and the level of consumption. Based on data from 28 Chinese provinces and cities from 1990 to 2007, Du Chuanzhong and Cao Yanqiao (2010) study the main factors of China's economic growth by building a panel regression model and conclude through comparison that exports can drive economic growth and that too large a government is detrimental to economic growth [5]. Jiang Hongli and Jiang Pengcheng (2019) measured the quality of economic growth in 30 provinces and cities in China from 2006-2016 and showed that fiscal decentralization significantly inhibited the quality of economic growth by suppressing technological innovation and thus the quality of economic growth, but as technological innovation improved, fiscal decentralization shifted back from inhibiting economic growth to promoting economic growth [8].

Scholars in different countries have done some research on technological innovation for economic growth, Jae-pyo Hong (2017) examined the Granger causality between R&D investment in the ICT industry and economic growth in Korea, and there is a two-way Granger causality between R&D investment in the ICT industry and economic growth, meaning that R&D investment in ICT is driven by economic growth and vice versa [7]. Deng Meiwei and Zhang Jifeng (2018) empirically analyse panel data from Japanese prefectures and argue that technological innovation can contribute to the quality improvement of Japan's economic growth, but that this driving effect has significant regional variability and that it is likely to weaken in the future [4]. Mahendhiran Nair, Rudra P. Pradhan and Mak B. Arvin (2020) conducted an empirical analysis of data from 1961-2018 for OECD countries and concluded that in the short term, the results of R&D and ICT on economic growth are inconsistent, depending on the specific use of R&D; in the long term, R&D and ICT on economic growth there is a temporal causal relationship [9].

In summary, technological innovation is a driver of economic growth, but its path of influence also requires consideration of other factors, such as the underlying factors of economic growth and the degree of government intervention. The effects vary according to the characteristics of technological innovation itself, with spatial and temporal differences.

2.2. Empirical Analysis Methods

2.2.1. Data selection and processing

The data for this paper was obtained from the EPS database, China Statistical Yearbook, and a total of 4092 data were processed and regressed for analysis. Regression analysis was carried out using Stata software and the data were strongly balanced. Next, considering the unevenness of China's regional economic development, a regression analysis was carried out on the 31 Chinese provinces as a whole and then grouped according to the middle, eastern and western economic zones.

According to the division of China's Seventh Five-Year Plan into regional economic zones, the eastern part includes 12 provinces and municipalities in Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi Zhuang Autonomous Region and Hainan; the middle part includes 9 provinces and municipalities in Shanxi, Inner Mongolia Autonomous Region, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan; the western part includes 10 provinces and municipalities in Chongqing Municipality, Sichuan, Guizhou, Yunnan, Tibet Autonomous Region, Shaanxi, Gansu, Qinghai, Ningxia Hui Autonomous Region and Xinjiang Uygur Autonomous Region.

2.2.2. Selection of models

C.W. Cobb and P.H. Douglas introduced the Cobb-Douglas production function, which is very widely used in analysing the contribution of various factors to economic growth. The traditional Cobb-Douglas function theory of economic growth assumes that capital input K and labour input L are the most important drivers for economic growth. The basic form is $Y_t = A_t K_t^{\alpha} L_t^{\beta} e^{\mu}$, the linear expression is $LnY_t = LnA_t + \alpha LnK_t + \beta LnL_t + \mu$.

The traditional theory of economic growth considered technological progress A as an exogenous variable, generally regarded as a fixed constant. Later, Romer proposed the theory of endogenous economic growth, in which the element of technological progress becomes an endogenous driver of economic growth, adding technological progress and institutional change to the two factors of capital and labour to form a four-factor model of economic growth. In the study of technological innovation inputs and outputs, the Cobb-Douglas production function is defined as $A_t = B_t R_t^{\alpha} P_t^{\beta} e^{\mu}$. The linear expression is $LnA_t = LnB_t + \alpha LnR_t + \beta LnP_t + \mu$, where R and P denote fiscal expenditure on science and technology (input) and the number of patents granted (output) respectively in this paper, A denotes technological innovation, μ represents the effect of random disturbances, and similarly, α and β denote the respective elasticity coefficients represented, with larger values indicating a more pronounced effect on technological innovation.

2.2.3. Interpretation of variables

Due to a large number of proxy variables for technological progress, two core variables are representing technological progress, *"sci"* for R&D input (science and technology input in fiscal expenditure) and *"patent"* for R&D output (number of patents granted). *"gdp"* is chosen to represent GDP (gross regional product) as the explanatory variable, which is the variable representing economic growth.

For the other control variables, *"invest"* represents capital input (investment in social fixed assets), *"employ"* represents labour input (urban employment), *"gov"* represents the level of government intervention (government fiscal expenditure as a proportion of regional GDP), *"impexp"* represents the degree of economic openness (total imports and exports of each region as a proportion of regional GDP), *"con"* stands for the level of consumption (total retail sales of social consumer goods). (See Table 1 below).

TABLE 1 VARIABLES DESCRIPTION

Variables	Name	Definition
gdp	GDP	Gross regional product
sci	R&D investment	Investment in science and technology
patent	R&D outcomes	Number of patents granted
invest	Capital input	Total social fixed asset investment
employ	Labour input	Number of employed persons in urban areas
gov	Level of government intervention	General budget expenditure/ GDP
impexp	Degree of economic openness	Total imports and exports/ GDP
con	Consumption level	Total retail sales of consumer goods

Where model (1) considers only physical capital input and labour input, model (2) adds science and technology R&D input and output to model (1), and model (3) adds other factors affecting economic growth. The specific equations are shown below.

$$Lngdp_{it} = \alpha_0 + \alpha_1 Lninvest_{it} + \alpha_2 Lnemploy_{it} \quad (1)$$

$$Lngdp_{it} = \alpha_0 + \alpha_1 Lninvest_{it} + \alpha_2 Lnemploy_{it} + \alpha_3 Lnsci_{it} + \alpha_4 Lnpatent_{it} \quad (2)$$

$$Lngdp_{it} = \alpha_0 + \alpha_1 Lninvest_{it} + \alpha_2 Lnemploy_{it} + \alpha_3 Lnsci_{it}$$

$$+\alpha_4 Lnpatent_{it} + \alpha_5 Lngov_{it} + \alpha_6 Lnimpexp_{it} + \alpha_7 Lncon_{it} + \mu \quad (3)$$

$Lngdp_{it}$ is the result of taking the logarithm of the gdp of a province in a given year, i stands for the province and t stands for the year. For example, $Lngdp_{1,2007}$ represents the logarithmic value of Beijing's GDP in 2007, which is 9.143487. The same can be obtained for other indicators.

3. Results and Discussion

3.1. Descriptive Statistics

As the units taken between the variables differ, the natural logarithm of each variable is taken in this paper in conjunction with the above measurement model, and Table 2 shows the results of the descriptive analysis before the logarithm of each variable.

Table 1 Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
gdp	18111.02	16003.5	342.19	89879.23
invest	12341.45	10501.23	270.3	55202.72
employ	953.5381	791.8282	41.2	5514.23
sci	769301.9	1014961	19260	8238900
patent	32622.07	53238.08	68	332652
gov	2592.276	1965.183	870.448	13791.61
impexp	2849.778	3419.091	157.83	16488.56
con	1741582	1.05e+07	125.12	9.77e+07

3.2. Granger Tests

To determine whether there is a causal relationship between technological innovation and economic growth, this paper conducted Granger causality tests on R&D investment, R&D outcomes and GDP respectively. In addition, the xtgranger command developed by Xiao Jiaqi, Juodis, Arturas, Yiannis Karavias and Vasilis Sarafidis was drawn upon for the Granger causality test, so that its testing ideas could be better utilised in the panel data[13].

Table 3 Granger Tests

Original hypothesis	P-value	Judgement
lnsci does not Granger-cause lngdp.	0.000	Reject
lngdp does not Granger-cause lnsci.	0.776	Accept
lnpatent does not Granger-cause lngdp.	0.000	Reject
lngdp does not Granger-cause lnpatent.	0.001	Reject

The null hypothesis is that X does not Granger Cause Y. If the p-value is less than 0.01 at 99% confidence level, the null hypothesis is rejected and vice versa. Based on this, it is clear from the results in Table 3 that R&D investment and the number of patents granted are Granger causes of economic growth; economic growth is not a Granger cause of R&D expenditure, but a Granger cause of the number of patents granted.

3.3. Regression Results

In this paper, the regression analysis of the linear relationship between the variables is carried out separately using a fixed-effects model. Overall, the goodness of fit of the models (1), (2) and (3) from Table 4 is good. Therefore, the results of the regressions are convincing. Nationally, all three models illustrate a significant contribution of capital, labour and R&D in science and technology to economic growth.

The results of model (2) show that R&D investment plays a positive role in economic growth and are significant at the 99% confidence level. Each additional unit of investment in R&D and each additional unit of a patent granted increases economic growth by 0.127 and 0.103 respectively. This suggests that the more government investment in R&D in science and technology within reason and the more patent licences passed, the faster a region is likely to grow economically.

As shown in model (3), capital, labour, investment in R&D and the number of patents granted remain significant after the inclusion of variables such as the degree of government intervention, exports and imports and consumption, thus establishing that the contribution of these four variables to economic growth is highly significant. However, the significance of labour and the number of patents granted decreases, which does not rule out the possibility of a slight error in the model.

For the control variables, the degree of government intervention and openness shows an uncorrelated relationship with economic growth. This differs from common sense and is thought to be a result of multicollinearity, as this paper mainly considers government-led R&D inputs. The level of consumption shows a positive relationship on economic growth, with each unit increase in consumption level leading to a 0.497 unit increase in GDP.

Table 4 Overall Results

VARIABLES	(1)	(2)	(3)
	lngdp	*lngdp*	*lngdp*
lninvest	0.475***	0.320***	0.162***
	(25.52)	(13.77)	(7.77)
lnemploy	0.477***	0.291***	0.066*
	(11.62)	(7.02)	(1.89)
lnsci		0.127***	0.059***
		(4.83)	(2.88)
lnpatent		0.103***	0.035**
		(5.41)	(2.29)
lngov			0.043

			(0.93)
lnimpexp			-0.009
			(-0.75)
lncon			0.497***
			(14.85)
Constant	1.990***	2.007***	1.833***
	(13.87)	(12.27)	(5.65)
Observations	341	341	341
R-squared	0.9509	0.9620	0.9782
F test	2984***	1935***	1938***

Notes: t-statistics in parentheses. *p-value<0.10, **p-value<0.05, ***p-value<0.01.

Looking at the sub-regions in Table 5, apart from some flaws in the model selection, capital and labour inputs have a positive impact on economic growth in all regions, except for the eastern and middle regions where labour inputs are insignificant. The coefficient for capital input shows that this positive impact is particularly evident in the middle region, followed by the western region.

For the two indicators of technological innovation, the impact of investment in science and technology on economic growth is particularly pronounced in the eastern region, followed by the middle region, while the western region shows an insignificant impact. The impact of the number of patent applications granted on economic growth is only evident in the eastern region, but not in the middle and western regions.

For the control variables, the results for the indicators of the degree of government intervention show negative and significant coefficients for the eastern region, meaning that a unit increase in the degree of government intervention reduces GDP by 0.257 units.

The results for openness show a negative correlation with economic growth in the eastern and middle regions and a positive correlation in the western region.

The level of consumption is positively correlated for both the middle and eastern regions and is significant at the 99% confidence level, with the coefficient showing the lowest in the middle region, the second highest in the eastern region and the highest in the western region.

TABLE 5 REGRESSION RESULTS BY REGION

Variable	East	Middle	West
lninvest	0.116***	0.238***	0.198***
	(4.94)	(4.22)	(4.09)
lnemploy	-0.086	0.104	0.111**
	(-1.54)	(1.13)	(2.59)
lnsci	0.135***	0.066*	-0.010
	(4.21)	(1.69)	(-0.25)
lnpatent	0.104***	0.049	0.007
	(4.60)	(1.35)	(0.36)
lngov	-0.257***	-0.026	0.060
	(-3.55)	(-0.18)	(1.01)
lnimpexp	-0.098***	-0.079**	0.050***
	(-4.02)	(-2.28)	(3.42)
lncon	0.536***	0.344***	0.540***
	(13.55)	(3.76)	(7.91)
_cons	4.471***	3.180***	0.879*
	(9.31)	(3.21)	(1.76)
Obs.	132	99	110
R-sq	0.9823	0.9470	0.4018
F test	1150.48***	382.91***	1070.48***

Notes: t-statistics in parentheses. *p-value<0.10, **p-value<0.05, ***p-value<0.01.

4. *CONCLUSIONS*

4.1. Results Analysis and Future Research

Based on panel data from 31 provinces and cities in China, this paper explores the role of technological innovation on China's economic growth and draws the following conclusions.

Firstly, capital input and labour input remain important contributors to economic growth. The empirical analysis shows that technological innovation inputs and outputs can contribute to economic growth to a certain extent, and technological innovation outputs also show a two-way Granger causality with economic growth. The role of technological innovation is becoming more and more prominent in today's green society. Technological innovation can promote economic growth by optimising industrial structure, reducing unnecessary energy consumption and reducing environmental pollution. The role of technological innovation can be analysed not only from the perspective of the government but also from the perspective of enterprises. However, in terms of the coefficient between capital, labour and innovation, the role of technological innovation in economic growth needs to be strengthened.

Secondly, concerning the level of government intervention, openness and the level of consumption. Too much government intervention in the economy does create scenarios that are contrary to the initial objectives. A general government budget above a certain level is not conducive to the healthy development of the market. This also suggests that, in the process of transforming economic development, the transformation of government functions should be accelerated and the size and expenditure of government should be appropriately reduced so that the government can better perform its service functions.

In addition, the role of China's import and export openness in economic growth has gradually decreased in recent years. The international trade market is risky and foreign boycotts against China have made foreign exports more difficult. Putting aside the errors introduced by the econometric analysis methods in this paper, the role of openness in driving economic growth has declined. In this paper, total retail sales of consumer goods are chosen to represent the level of consumption. More total retail sales

of consumer goods mean more consumer demand, which has a clear driving effect on economic growth.

Finally, the results are seen from a sub-regional perspective. Due to the heterogeneity of China's regional development, the results for the various indicators of economic growth are different. Capital inputs contribute to economic growth in all three regions and, leaving aside the issue of errors in the regression methodology, labour inputs, as the most basic factor of production, still contribute more to the economy. However, it cannot be ruled out that in the eastern and middle regions, which rely on technological innovation and progress and thus economic growth, the contribution of labour inputs to economic growth is instead lower. The results of combining innovation inputs and outputs can be confirmed in the eastern region, where the number of science and technology inputs and patents granted can contribute to economic growth. Since this paper focuses on government-led R&D inputs, the impact of R&D inputs on economic growth in the middle and western regions may not be significant. Given the different types of patent applications and the lag in the impact of patent applications on economic growth, the results across regions are not as good as they could be, and this is an area for further research and improvement. Future research will build on the shortcomings of this paper so that the relationship between technological innovation and economic growth can be analysed more scientifically and comprehensively.

4.2. Policy Recommendations

In terms of national strategy, government departments need to continue to promote the deepening of the innovation system, as innovation remains the primary goal of economic development. There is still a need to continue to promote the construction of a technological innovation system and to increase the financial investment in technological innovation. Promoting the effective realisation of the results of technological innovation, as well as increasing the rate of conversion of the final implementation of patent results, is the only way to ensure that the output of technological innovation contributes to economic growth.

Encouraging companies to innovate through technology is also one way to improve the quality of China's economic growth. The current form of international trade is still uncertain and the world is forced to protect its industries due to the impact of the pandemic, especially the innovative output of some high-tech enterprises. The birth of the Beijing Stock Exchange is conducive to the country's support for the development of innovative small and medium-sized enterprises through the establishment of the New Third Board market, which will further enhance the technological innovation ability of enterprises and thus achieve higher quality economic development.

In terms of sub-regional development, there is a need to further strengthen inter-regional cooperation and to capitalise on the locational advantages of different regions, thereby reducing the impact of regional development heterogeneity.

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