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O. Economic development, innovation, technological change, and growth

ИЗУЧЕНИЕ ВЗАИМОСВЯЗИ МЕЖДУ НАУЧНЫМИ ИССЛЕДОВАНИЯМИ, ТЕХНОЛОГИЧЕСКИМИ ИННОВАЦИЯМИ И ЭКОНОМИЧЕСКИМ РАЗВИТИЕМ КИТАЯ

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Изучена взаимосвязь между инвестициями в научные исследования Китая, технологическими инновациями и экономическим развитием за последние 20 лет. Проведены эмпирические исследования для последовательного анализа временных рядов с использованием теста единичного корня, теста коинтеграции и анализа модели байесовского сетевого графика вероятностей. Результаты исследований показывают, что существуют долгосрочные сбалансированные отношения коинтеграции между инвестициями в научные исследования, технологическими инновациями и экономическим развитием.

Ключевые слова: технологические инновации; инвестиции в исследования; экономическое развитие; коинтеграционный тест; байесовский сетевой график вероятностей.

RESEARCH ON THE CORRELATION BETWEEN CHINA'S SCIENTIFIC RESEARCH, TECHNOLOGY INNOVATION AND ECONOMIC DEVELOPMENT

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The purpose is to study the relationship between China's scientific research investment, technological innovation and economic development in the past 20 years. This article uses empirical research to sequentially analyze the time series using unit root test, cointegration test, and Bayesian network graph model analysis. The research results show that there is a long-term balanced cointegration relationship between scientific research investment, technological innovation and economic development.

Keywords: technological innovation; research investment; economic development; cointegration test; Bayesian network probability graph.

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Introduction

There is a complicated relationship between scientific research investment, technological innovation and economic development. From previous research we can know that there is a correlation between scientific research investment and technological innovation, that is, the significant works of scientific research investment are used for technological innovation [1]. However, what kind of influence will the research investment and technological innovation have on economic development? This is the main purpose of this article. In order to explore this internal mechanism, the authors of this paper will use the relevant indicators of scientific research investment, technological innovation and economic development, use cointegration analysis models to analyze the internal connections, and use Bayesian network probability graph to intuitively illustrate the degree of mutual influence.

Since the classical regression analysis model is based on stable variables, but the time series with long-term statistics are mostly non-stationary series, we cannot directly use the classic regression model, otherwise the experimental results may appear regression fallacy. Therefore, in terms of research methods, this paper first uses the unit root test model to test the stability of the data series. According to the analysis results of the unit root test model, the cointegration test model is used to test the sequences to verify the stability relationship between the sequences. To ensure the applicability of the classical regression model, a residual coefficient matrix is obtained. Finally, a Bayesian network probability graph was constructed to intuitively show the simultaneous causal relationship between «scientific research investment, technological innovation and economic development», and theoretical analysis of the results.

Theoretical research

Research methods. *Unit root test.* The unit root test is a special method for the stability test proposed for macroeconomic data series and monetary and financial data series [2; 3]. There are many methods for unit root test, including ADF (augmented Dickey – Fuller) test, PP (Phillips and Perron) test, NP (Neuman-Pearson) test, etc.

The object of this article is panel data. The panel data model needs to check the stability of the data before regression analysis. The unit root test model is expressed by the following equation [3]:

$$X_t = \alpha + \beta X_{t-1} + \mu_t,$$

where α is the panel data dimension, β is the autoregressive coefficient, and μ_t is the random error term.

Cointegration test. Non-stationary sequences are likely to cause regression fallacy. The significance of cointegration is to test whether the causal relationship described by their regression equation is regression fallacy, that is, to test whether there is a stable relationship between variables [2; 5]. Therefore, the causality test for non-stationary sequences is the cointegration test.

After the unit root test, a VAR (vector autoregression) model is constructed, and the sequence is cointegrated using a Johansen-based cointegration test [4]. Test statistic p-value is

$$P = -2\sum_{i=1}^{N} \log(p_i) \to x^2(2N),$$

where p_i is the p-value of the Johansen cointegration test for the i section; if the Trace statistic is greater than the critical value, and the p-value is less than the significance level of 5 %, it is determined to reject the null hypothesis of cointegration test. That is, there is a cointegration relationship [5].

Bayesian Network Probability Graph Model. Bayesian network is a probability graph model, and its network topology is a directed acyclic graph (DAG) [6].

For any random variable, its joint probability can be obtained by multiplying the respective local conditional probability distributions [7]:

$$p(x_1, \ldots, x_K) = p(x_K | x_1, \ldots, x_{K-1}) \ldots p(x_2 | x_1) p(x_1)$$

The Bayesian network satisfies the partial Markov property. This property can simplify the network joint distribution to a smaller form. Let $G = (I, E)$ represent a directed acyclic graph (DAG), where I represents the set of all nodes in the graph [8], and E represents the set of directed connected line segments, and let $x = (x_i)$, $i \in I$, is a random variable represented by a node i in the directed acyclic graph. If the joint probability of node x can be expressed as

$$p(x) = \prod_{i \in I} p(x_i | x_{pa(i)}).$$

Randow variable x is called a Bayesian network relative to the directed acyclic graph G, where $pa(i)$ represents the «cause» of node i [8].

Selection of indicators and data sources. Limited to the availability of data, this article uses relevant data such as China's scientific research input, technological innovation, and economic indicators from 1996 to 2017, and analyzes the correlation between R&D input, innovation output, and economic development. R&D investment indicators are expressed in terms of R&D expenditures (RD), technical innovation indicators are expressed in terms of patent application (PA) and technology market turnover (TMT), and economic development indicators are expressed in GDP.

The data in this article comes from the 1997–2018 China Statistical Yearbook, China Financial Statistics Yearbook, China Science and Technology Statistics Yearbook, and annual statistical bulletins published by the National Bureau of Statistics of China.

Empirical research

Data collection. By consulting the China Statistical Yearbook, the four main indicators from 1996 to 2017 were selected: R&D expenditures, expressed in RD; patent application authorizations, expressed in PA; technology market turnover, expressed in TMT; value in GDP.

First, draw the following charts based on the acquired data, as shown in fig. 1–4.

As can be seen from the above figure, since 1996, four indicators representing China's overall investment in scientific research, technological innovation, and economic development have shown a trend of increasing with time. We call these four data indicators time series.

The purpose of this article is to study the long-term stable relationship and the strength of the interaction between these four sequences [9]. As can be seen from the above four figures, this sequence may be a non-stationary sequence. In order to prevent «regression fallacy», the unit root test should be performed on the 4 sequences first.

Unit root test. Because the research object is a long time series, in order to prevent the emergence of regression fallacy, the data must be tested for stationarity. In order to eliminate the effects of heteroscedasticity and different dimensions, this paper chooses to take the natural logarithm of the data columns [10]. The four data columns are named lnRD, lnPA, lnTMT, and lnGDP, as shown in table 1.

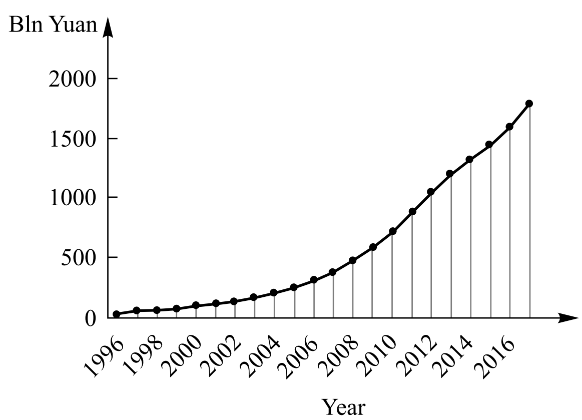

Fig. 1. R&D investment

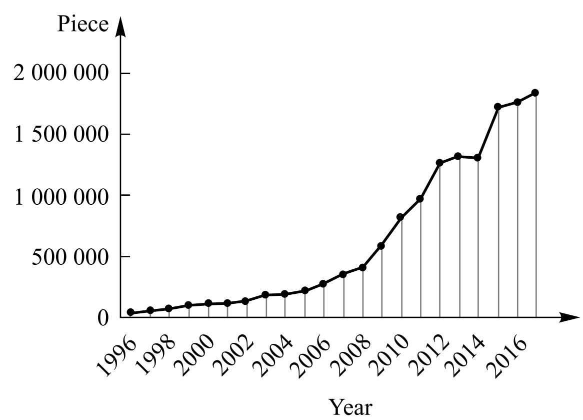

Fig. 2. Number of patent applications

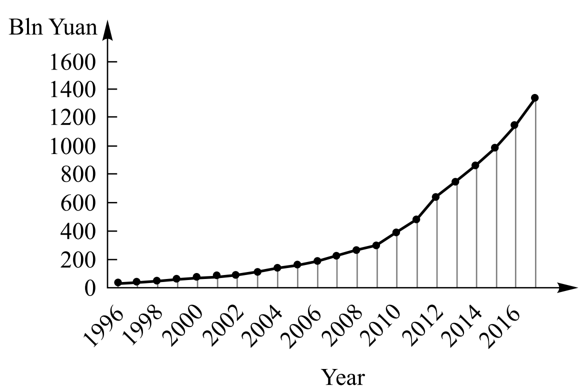

Fig. 3. Technology market turnover

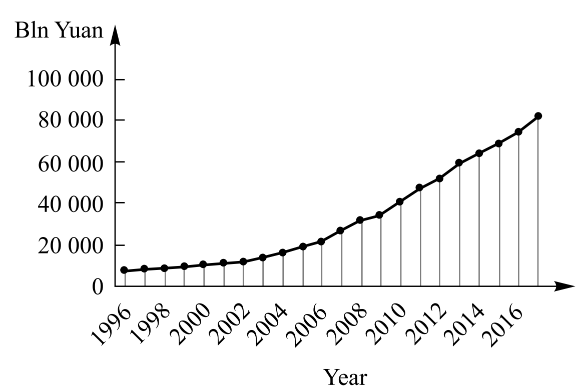

Fig. 4. Gross domestic product

Table 1

Original value time series

Year	lnRD	lnPA	lnTMT	lnGDP
1996	5.6058	10.6869	5.7038	11.1729
1997	6.1769	10.8394	5.8608	11.2769
1998	6.3119	11.1256	6.0776	11.3433
1999	6.5205	11.5145	6.2596	11.4040
2000	6.7976	11.5650	6.4785	11.5050
2001	6.9494	11.6462	6.6631	11.6051
2002	7.1605	11.7936	6.7845	11.6980
2003	7.3393	12.1130	6.9893	11.8191
2004	7.5839	12.1560	7.1959	11.9822
2005	7.8038	12.2737	7.3467	12.1278
2006	8.0074	12.4987	7.5055	12.2845
2007	8.2188	12.7708	7.7084	12.4905
2008	8.4373	12.9287	7.8880	12.6573
2009	8.6660	13.2742	8.0193	12.7394
2010	8.8626	13.6107	8.2705	12.9030
2011	9.0696	13.7752	8.4688	13.0671
2012	9.2397	14.0428	8.7698	13.1606
2013	9.3798	14.0878	8.9185	13.2929
2014	9.4739	14.0799	9.0568	13.3712
2015	9.5589	14.3568	9.1938	13.4386
2016	9.6599	14.3773	9.3420	13.5145
2017	9.7760	14.4233	9.5048	13.6180

The method of sequence stationarity test is to test whether the unit root exists in the sequence. In this paper, the ADF test and the PP test are used to comprehensively determine whether to accept the null hypothesis based on the *t*-statistic and *p*-values of the test results. The «Adj. *t*-stat.» refers to adjusted *t*-statiscics, «prob.» is probability value. The results are shown in table 2.

Table 2

Unit root test of original value series

Stationarity test lnRD		Unit root test of original value series				Unit root test for first-order difference sequences			
		lnRD	lnPA	lnTMT	lnGDP	lnRD	lnPA	lnTMT	lnGDP
ADF test	Adj. *t*-stat.	0.49	–0.07	3.44	–0.83	0.09	–0.64	–2.31	–0.69
	Prob.*	1.00	0.99	1.00	0.95	0.96	0.84	0.41	0.83
PP test	Adj. *t*-stat.	0.40	–0.64	11.29	6.31	1.11	–8.49	–2.31	–3.97
	Prob.*	1.00	0.94	1.00	1.00	0.92	0.00	0.41	0.03
Result		–	–	–	–	–	–	–	–

*Denotes rejection of the hypothesis at the 0.05 level.

According to table 2, it can be known that under the ADF test and the PP test, the original value series has a significance level *p*-value > 0.9, and the original hypothesis cannot be rejected, that is, the unit root exists, and it is determined as a non-stationary series. Then perform a «unit root test» on the first-order difference sequence. Although the PA and GDP sequences reject the null hypothesis under the PP test, but they accept the null hypothesis under the ADF test, so it is determined that there is a unit root, which is a non-stationary sequence. Both the RD and TMT sequences accept the null hypothesis in the unit root test of the first-order difference sequence. Therefore, it can be determined that they have unit roots and are non-stationary sequences.

After the above experiments, it was decided to perform a unit root test on the second-order difference sequence of the original sequence. The results are shown in table 3. All sequences passed the significance level test of 1 to 5 % under the ADF and PP test forms. Determine the second-order difference sequence as a stationary sequence [11].

Table 3

Second-order difference unit root test

Stationarity test lnRD		Unit root test for second-order difference sequences			
		lnRD	lnPA	lnTMT	lnGDP
ADF test	Adj. *t*-stat.	–3.20	–2.78	–6.58	–5.16
	Prob.*	0.01	0.01	0.00	0.00
PP test	Adj. *t*-stat.	–12.71	–21.93	–6.58	–6.09
	Prob.*	0.00	0.00	0.00	0.00
Result		+	+	+	+

*Denotes rejection of the hypothesis at the 0.05 level.

The reason for the judgment is that according to the parameter domain given by EViews, the absolute value of *p*-value and *t*-statistic are compared, and both are within the parameter domain, then the null hypothesis can be rejected, and the second-order difference sequence has no unit root.

According to the above experiments, the following conclusions can be drawn: the original value sequence in this paper is a non-stationary sequence, and the second-order difference sequence is a stationary sequence.

According to the unit root test result, the original value series is the same order single integer non-stationary series, which meets the prerequisites of the cointegration test. Therefore, this article decides to further study and perform cointegration test to determine whether there is long-term stability between the series relationship.

Cointegration test. First, import all original value sequences in EViews software and establish a VAR model. After experiments, when the lag length is 3, LR, FPE, AIC, SC, and HQ are all truncated to 3rd order. The data range is from 1996 to 2007 and the variables are lnKD, lnPA, lnTMT, and lnGPD. The results are shown in table 4.

Table 4

Selection criteria for VAR lag length

Lag	LogL	LR	FPE	AIC	SC	HQ
0	–777.5254	NA	6.28e + 30	82.26583	82.46466	82.29948
1	–678.6811	145.6652	1.08e + 27	73.54538	74.53953	73.71363
2	–622.4666	59.17326	2.07e + 25	69.31227	71.10173	69.61512
3	–518.8935	65.41453*	5.01e + 21*	60.09406*	62.67884*	60.53151*

*Indicates lag order selected by the criterion.

According to the above experimental results, the lag length of the updated initial VAR model is 3. This article uses the Johansen cointegration test to perform a cointegration test on the original value series [5]. Select «Cointegration test» in the EViews software, the test parameters are the cointegration equation has the «Intercept term», the VAR model has the «Linear trend», click «Ok» to get the experimental results. The test results are shown in the table 5.

Table 5

Cointegration test results

Variable	Null hypothesis	Trace statistic	Prob.**	Max-Eigen statistic	Prob.**	Result
lnRD, lnPA	None*	26.24119	0.0008	20.37702	0.0048	Cointegration
	At most 1*	5.864171	0.0154	5.864171	0.0154	

Ending table 5

Variable	Null hypothesis	Trace statistic	Prob.**	Max-Eigen statistic	Prob.**	Result
lnRD, lnGDP	None*	25.72202	0.0010	20.52521	0.0045	Cointegration
	At most 1*	5.196807	0.0226	5.196807	0.0226	
lnPA, lnGDP	None*	40.71469	0.0000	33.10652	0.0000	Cointegration
	At most 1*	7.608169	0.0058	7.608169	0.0058	
lnPA, lnTMT, lnGDP	None*	49.40430	0.0001	32.44380	0.0009	Cointegration
	At most 1*	16.96050	0.0299	11.69622	0.0226	
	At most 2*	5.264275	0.0218	5.264275	0.0218	
lnRD, lnPA, lnTMT, lnGDP	None*	252.3620	0.0001	125.5019	0.0000	Cointegration
	At most 1*	126.8601	0.0000	67.59719	0.0000	
	At most 2*	59.26290	0.0000	40.12876	0.0000	
	At most 3*	19.13414	0.0000	19.13414	0.0000	

*Denotes regection of the hypothesis at the 0.05 level; **MacKinnon – Haug – Michels (1999) p-values.

Johansen's test hypothesis says that there is no cointegration relationship in the test results. From the cointegration test results, it can be known that lnRD and lnPA reject the null hypothesis at a significance level of 5 %, and it can be determined that there is a «cointegration equation» that can describe the cointegration relationship [7]. It can also be known that lnRD, lnGDP, lnPA, and lnTMT each reject the null hypothesis at a significance level of 5 %, and it can be determined that there is a cointegration relationship, that is, between research investment, technological innovation, and economic development there is a long-term stable mutual influence relationship.

Bayesian network probabilistic graph model analysis. During the cointegration test, the correlation coefficient matrix of the VAR model can be obtained through EViews software, as shown in table 6.

Table 6

Correlation coefficient matrix of VAR model

Factor	lnGDP	lnPA	lnRD	lnTMT
lnGDP	1.0000	0.1246	0.5534	0.0822
lnPA	0.1246	1.0000	0.6415	0.9117
lnRD	0.5534	0.6415	1.0000	0.6068
lnTMT	0.0822	0.9117	0.6068	1.0000

According to the above-mentioned residual correlation coefficient matrix, the dependency and directivity of the causal relationship between the variables over the same period are calculated, and a static Bayesian network diagram is drawn. The results are shown in fig. 5.

The following conclusions can be drawn from fig. 5:

1. Technology market turnover promotes R&D investment, which shows that RD's regression model:

$$\ln RD = 0.6068 \cdot \ln TMT.$$

Technology market turnover represents the market value of technology products, which can directly promote enterprises' investment in research and development, and is the main reason for enterprises to invest in technology research and development.

2. The R&D investment and technology market promote innovation output, and the regression model of $\ln PA$ can be obtained:

$$\ln PA = 0.6415 \cdot \ln RD + 0.9117 \cdot \ln TMT.$$

R&D investment is the direct cause of technological innovation, and the turnover of the technology market can directly promote technological innovation, and can also promote technological innovation output by promoting research and development investment.

3. RD, TMT, PA can promote GDP, and a regression model of $\ln GDP$ can be obtained:

$$\ln GDP = 0.5534 \cdot \ln RD + 0.0822 \cdot \ln TMT + 0.1246 \cdot \ln PA.$$

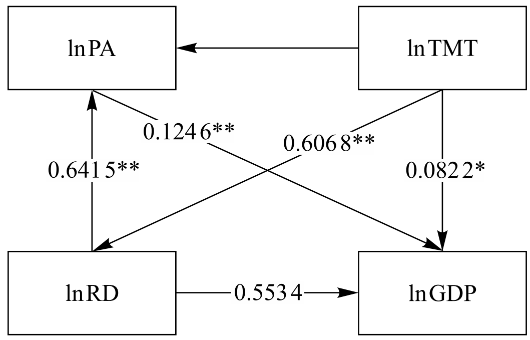

Fig. 5. Static Bayesian network diagram
(** and * indicate statistical significance at the 1 and 5 % levels, respectively)

R&D investment, technology market turnover, and technological innovation can promote the growth of national GDP. The promotion effect of lnPA on lnGDP has a «significant level of 1 %», indicating that technological innovation is the core factor that promotes GDP growth. The effect of lnTMT on lnGDP is significant at the 5 % level, indicating that the technology market turnover is an important and direct factor for GDP growth. R&D investment has a weak role in promoting GDP, but R&D investment can indirectly promote GDP growth by promoting technological innovation.

Conclusion

This article uses 22 years of data from the 1997–2018 China Statistical Yearbook to study the inherent correlation between China's scientific research investment, technological innovation and economic development in the past 20 years. In this paper, the unit root test, cointegration test, VAR model analysis, and Bayesian network model analysis of the sequence are performed in order, and the following conclusions are drawn:

1) research investment, technological innovation and economic development have long – term stable internal links with each other, and the three can promote each other;

2) scientific research investment is the core cause of technological innovation;

3) technological innovation is the direct cause of economic development, and it has significantly promoted economic growth;

4) good economic development can also promote R&D investment and form a various circle.

The research results in this article indicate the inherent influence mechanism between research investment, technological innovation and economic development. Technological innovation has a strong direct role in promoting economic development. It shows that China has consistently implemented the strategy of innovation-driven development and the policy orientation of building an innovative society, which has promoted the sustainable economic growth of the whole society. The continued promotion of technological innovation will have contribute to national economic development.

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