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Empirical Study on the Impact of Energy Consumption on GDP in Guangdong Province

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Abstract: Energy consumption and GDP in Guangdong are closely related. This paper uses time series data of Guangdong's GDP and energy consumption from 2002 to 2021, and applies methods such as unit root test, cointegration analysis, multicollinearity test and correction, and sequence correlation test and correction to study the impact of the consumption of various components of terminal energy on Guangdong's GDP. The results show that (1) the logarithm of coal consumption (LnX1) and the logarithm of oil consumption (LnX2) have no significant impact on the logarithm of GDP (LnGDP) at the 5% significance level; (2) the logarithm of electricity consumption (LnX3) and the logarithm of other energy consumption (LnX4) have a significant impact on the logarithm of GDP (LnGDP) at the 5% significance level, and on average, an increase of 1% in electricity consumption and other energy consumption will increase Guangdong's GDP by 0.698% and 0.507%, respectively; (3) the logarithm of coal consumption (LnX1) and the logarithm of oil consumption (LnX2) have no significant impact on the logarithm of GDP (LnGDP) in the current period at the 5% significance level, but have a significant positive impact with a lag of one year. Based on these findings, policy recommendations are proposed.

Keywords: Guangdong Province, Energy Consumption, GDP, Cointegration Analysis

1. Introduction

During the 14th Five-Year Plan period, the development of energy both domestically and internationally has become increasingly complex. The goals of carbon peaking and carbon neutrality have raised higher requirements for energy development in China. Guangdong Province has maintained continuous GDP growth for over 30 years, ranking first in the country. On the one hand, the total energy consumption in Guangdong Province is enormous; on the other hand, the province has a shortage of energy resources and a low self-sufficiency rate, resulting in a severe energy supply and demand imbalance.

The purpose of this study is to explore the quantitative relationship between GDP and energy consumption in Guangdong Province, analyze its influencing factors and trends, and provide scientific basis and decision-making support for energy and economic development in Guangdong Province. The specific objectives are as follows: (1) Determine the quantitative relationship between GDP and energy consumption in Guangdong Province, analyze its changing trends and influencing factors; (2) Explore the changes in the energy consumption structure in Guangdong Province and analyze its impact on GDP; (3) Provide policy recommendations for energy and economic development in Guangdong Province to promote sustainable development.

This study is of great significance for promoting energy and economic development in Guangdong Province. Firstly, in-depth research on the quantitative relationship between GDP and energy consumption in Guangdong Province can provide scientific basis for formulating reasonable energy policies. Secondly, exploring the changes in the energy consumption structure and spatial distribution characteristics in Guangdong Province can provide reference for optimizing energy structure and adjusting regional economic structure. Finally, providing policy recommendations for energy and economic development in Guangdong Province can provide guidance for promoting sustainable development.

2. Literature Review

2.1. Study on Energy Consumption in Guangdong Province

Domestic scholars have made many achievements in the study of energy consumption. Tian Zhonghua and Chen Weili proposed that cultivating new energy-saving points must be based on scientific and technological progress and innovation, and believed that scientific and technological progress can effectively reduce the peak value of energy consumption per unit of GDP [1]. Lan Mengxin pointed out that different modes of energy consumption have different economic impacts on different regions, and targeted measures must be taken to limit energy consumption and optimize energy consumption structure [2]. Tian Zhiyong et al. believed that the two important factors affecting the energy consumption per unit of GDP are industrial structure and energy consumption structure [3]. Chen Jia and Zhang Renshou believed that high-energy-consuming, low-efficiency, and heavily polluting industries should be eliminated, and efforts should be made to promote the upgrading and optimization of industrial structure and improve the system energy efficiency [4].

2.2. Research on the Impact of Energy Consumption on GDP

Domestic scholars have different views on the relationship between energy consumption and GDP. Xu Limeng conducted Granger tests and impulse response function analysis on 11 EU countries, and concluded that non-renewable energy promotes short-term economic growth, while renewable energy consumption has long-term promoting effects on the economy [5]. Shi Xianguang used time series data on energy consumption in Henan Province from 1978 to 2008 to empirically analyze the impact of energy consumption on economic growth, and the results showed that energy consumption has a significant impact on GDP growth [6]. Zhong Shuai pointed out that the increase in energy consumption has a promoting effect on GDP in this stage, and suggested optimizing the industrial structure and increasing the development of new energy [7]. Cheng Fang believes that rapid economic growth cannot be achieved without the assistance of capital and energy consumption [8].

2.3. The Mutual Influence Between Energy Consumption and GDP

There is evidence to suggest that the impact of energy consumption on GDP is not one-way, but rather a mutually influential relationship. For example, Wang Fei believes that there is a significant correlation between energy consumption and economic GDP. She believes that a rational allocation of energy resources plays an important role in promoting GDP growth and improving energy consumption efficiency. Only with improved energy utilization efficiency can the national economy achieve healthy and stable development [9]. Zhang Jie and Wang Zhiwen conducted a correlation analysis on the statistical data of GDP and energy consumption in Liaoning Province from 1990 to 2013 and found a positive linear relationship between GDP and total energy consumption [10].

2.4. Research Methods for Modeling

The paper used unit root tests to examine the stationarity of the time series and applied the Engle-Granger two-step method to conduct cointegration analysis on the data. Dickey made a significant contribution by introducing the concept of unit roots and unit root testing methods, providing important tools and theoretical foundations for time series analysis. Dickey-Fuller proposed the Dickey-Fuller test, which introduces lagged difference terms to determine whether a time series data has a unit root, thus determining its stationarity [11]. R. A. Fisherd first introduced the method of eliminating multicollinearity in 1925 [12]. Engle-Granger proposed the concept and method of cointegration and developed the Engle-Granger cointegration model for testing and estimating long-term equilibrium relationships [13]. Yao Yang and Qi Shaozhou believe that if a certain linear combination of two or more time series vectors of the same order can result in a stationary error sequence, then they have a long-term cointegration relationship. However, before conducting cointegration analysis, it is necessary to test the order of integration of the variables to prevent spurious regression [14]. Lin Boqiang analyzed various factors affecting China's energy demand based on cointegration and concluded that energy consumption, GDP, energy prices, and structural changes have a long-term equilibrium relationship [15]. John William Tukey first proposed the method of eliminating sequence correlation in 1949 [16].

Overall, the impact of energy consumption on GDP is a complex issue, and different research methods and data samples may yield different results. However, most studies suggest that there is a certain positive correlation between energy consumption and economic growth, especially in the short term. Therefore, in order to achieve sustainable development, we need to actively promote energy conservation and substitution while improving economic growth, in order to reduce the impact on the environment.

3. The Current Situation of Energy Consumption and GDP in Guangdong Province

3.1. The Final Energy Consumption in Guangdong Province Has Continued to Increase

The final energy consumption in Guangdong Province has increased from 108.6168 million tons of standard coal in 2002 to 359.5563 million tons of standard coal in 2021, an increase of 2.31 times in 20 years. It has increased relative to the previous year every year, with an average annual increase of 12.16%, as shown in Figure 1.

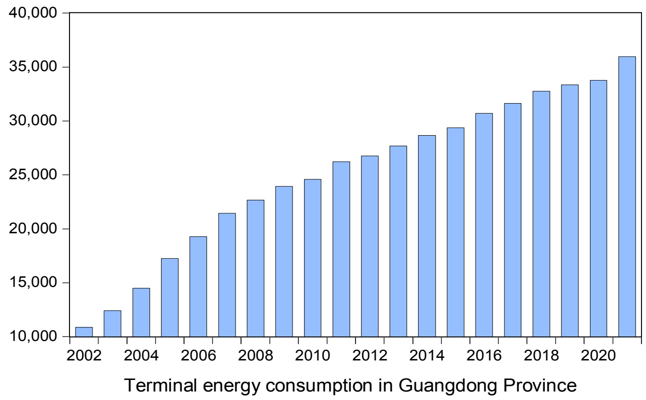

Figure 1. *Terminal energy consumption in Guangdong Province from 2002 to 2021 (unit: 10,000 tons of standard coal).*

3.2. Guangdong Province's Terminal Energy Consumption Structure Continues to Optimize

Terminal energy consumption is divided into four categories: raw coal consumption, oil consumption, electricity consumption, and other energy consumption. The proportion of raw coal and oil consumption is decreasing, while the proportion of electricity and other energy consumption is increasing, as shown in Figure 2.

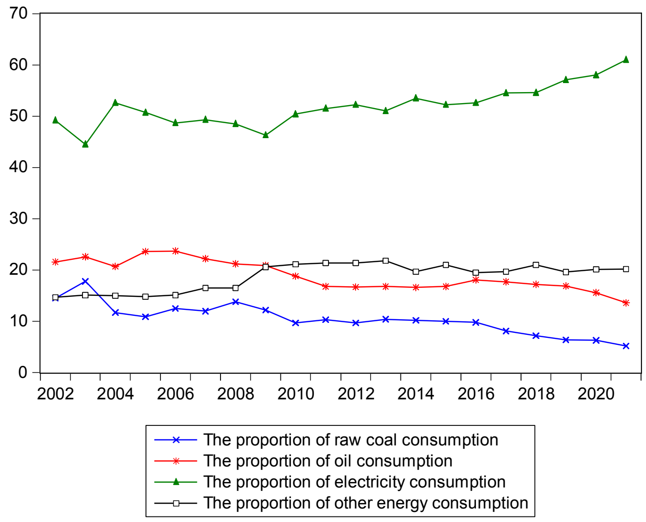

Figure 2. *Energy consumption structure of end-use sectors in Guangdong Province from 2002 to 2021 (unit: %).*

(1) The proportion of raw coal consumption has decreased overall. The proportion of raw coal consumption in Guangdong Province's terminal energy consumption has decreased from 14.5% in 2002 to 5.2% in 2021, a decrease of 9.3% over 20 years, with an average annual decrease of 0.489 percentage points. Except for the five years of 2003, 2006, 2008, 2011, and 2013, which saw an increase in year-on-year comparison, the proportion has decreased in other years.

(2) The proportion of oil consumption has decreased overall. The ratio of oil consumption to terminal energy consumption in Guangdong Province decreased from 21.6% in 2002 to 13.6% in 2021, a decrease of 8% over 20 years, with an average annual decrease of 0.421 percentage points. Except for the five years of 2003, 2005, 2006, 2015, and 2016, which saw an increase in year-on-year comparison, the proportion decreased in other years.

(3) The proportion of electricity consumption has gradually increased. The proportion of electricity consumption in Guangdong Province to the total energy consumption has increased from 49.2% in 2002 to 61% in 2021, an increase of 11.8% over 20 years, with an average annual increase of 0.621 percentage points. Except for seven years, namely 2003, 2005, 2006, 2008, 2009, 2013, and 2015, which saw a decrease in the proportion compared to the previous year, the proportion has increased in other years.

(4) The proportion of other energy consumption is gradually increasing. The proportion of other energy consumption to final energy consumption in Guangdong Province increased from 14.7% in 2002 to 20.2% in 2021, an increase of 5.5% over 20 years, with an average annual increase of 0.289 percentage points. Except for the five years of 2004, 2005, 2014, 2016, and 2019, which saw a decrease in year-on-year comparison, the proportion increased or remained unchanged in other years.

3.3. The Consumption of Various Components of Terminal Energy in Guangdong Province Has Increased to Varying Degrees

The consumption of the four major categories of terminal energy has been increasing from 2002 to 2021, with electricity consumption and other energy consumption showing double-digit growth, as shown in Figure 3.

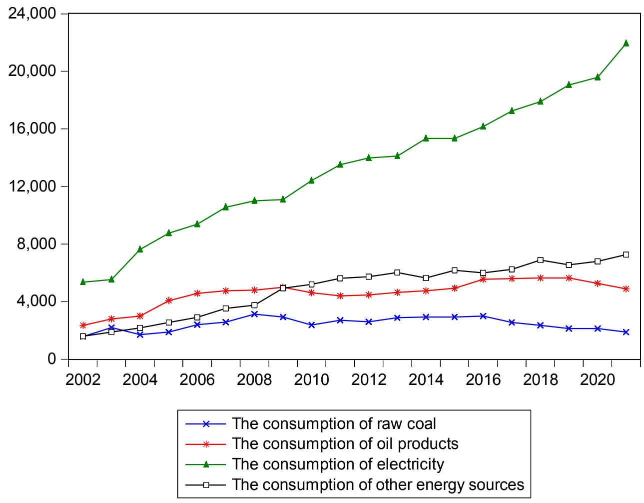

Figure 3. *Consumption of various components of final energy in Guangdong Province from 2002 to 2021 (unit: 10,000 tons of standard coal).*

(1) The consumption of raw coal increased from 15.74944 million tons of standard coal in 2002 to 18.69693 million tons of standard coal in 2021, an increase of 18.71% over 20 years, with an average annual increase of 0.985%.

(2) The consumption of oil products increased from 23.46123 million tons of standard coal in 2002 to 48.89966 million tons of standard coal in 2021, an increase of 108.43% over 20 years, with an average annual increase of 5.71%.

(3) The consumption of electricity increased from 53.43947 million tons of standard coal in 2002 to 219.3293 million tons of standard coal in 2021, an increase of 3.104 times over 20 years, with an average annual increase of 16.34%.

(4) The consumption of other energy sources increased from 15.96667 million tons of standard coal in 2002 to 72.63037 million tons of standard coal in 2021, an increase of 3.549 times over 20 years, with an average annual increase of 18.68%.

3.4. Continuous Growth of GDP in Guangdong Province

The nominal GDP of Guangdong Province has increased from 1360.189 billion yuan in 2002 to 12,436.967 billion yuan in 2021, a growth of 8.14 times over the past 20 years, with an average annual growth rate of 42.86%, as shown in Figure 4.

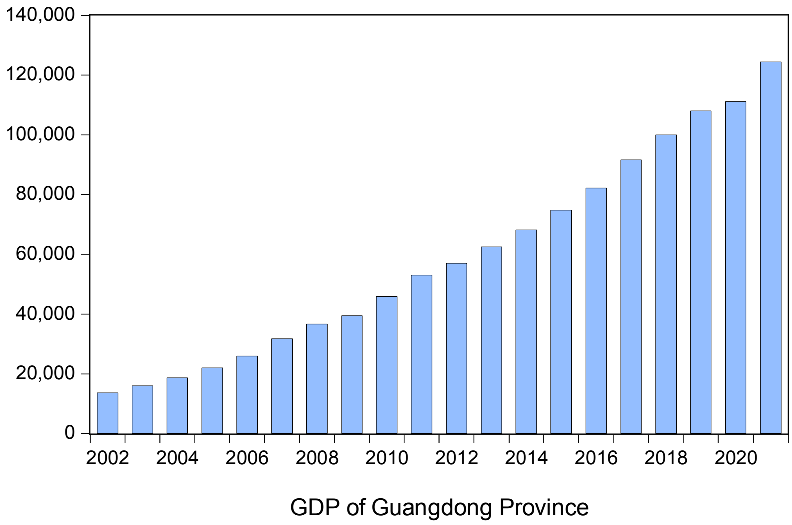

Figure 4. *GDP of Guangdong Province from 2002 to 2021 (unit: RMB 100 million).*

3.5. The GDP of Guangdong Province and the Consumption of Each Component of Final Energy Have a Common Trend of Change

Since the unit of consumption for each component of final energy is 10,000 tons of standard coal and the unit of GDP is 100 million yuan, the dimensions of the two are different. Therefore, in order to compare them, the logarithm of both quantities is taken. The logarithm of Guangdong's GDP and The logarithm of the consumption of each component of final energy both show an upward trend, as shown in Figure 5.

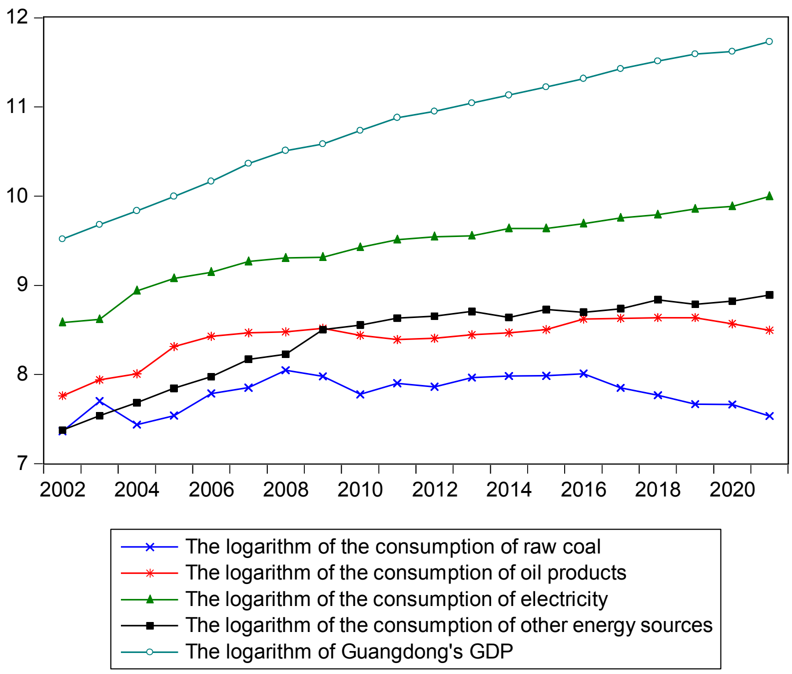

Figure 5. *Logarithmic plot of GDP and consumption of various terminal energy components in Guangdong Province from 2002 to 2021.*

4. Empirical Analysis

4.1. Data Source

The data on the consumption and structure of terminal energy in Guangdong Province from 2002 to 2021 were obtained from the Guangdong Statistical Yearbook (2022). The consumption of each component of terminal energy in Guangdong Province from 2002 to 2021 was calculated based on the terminal energy consumption and its structure. The data on the GDP of Guangdong Province from 2002 to 2021 were obtained from the Guangdong Statistical Yearbook (2022). The logarithms of the GDP and the consumption of each component of terminal energy from 2002 to 2021 were calculated based on the above data.

4.2. Unit Root Test

To avoid the phenomenon of "spurious regression", all variables were first subjected to unit root tests. ADF test was used for unit root testing to determine whether each variable is stationary. The results of the ADF test are shown in Table 1.

Table 1. *Test results of ADF test of each variable.*

Test variable	Inspection form	ADF statistics	1% significance level threshold	D.W value	p value	conclusion
lnX1	(C,0,0)	-2.416780	-3.831511	1.742785	0.1505	unstable
lnX2	(C,0,1)	-2.927496	-3.857386	2.005728	0.0617	unstable
lnX3	(C,0,0)	-2.381690	-3.831511	2.261517	0.1594	unstable
lnX4	(C,0,1)	-4.007375	-3.857386	1.866704	0.0074	stable
lnGDP	(C,0,0)	-4.901471	-3.831511	2.099987	0.0011	stable
ΔlnX1	(0,0,0)	-5.700376	-2.699769	1.348851	0.0000	stable
ΔlnX2	(0,0,0)	-2.720547	-2.699769	2.255214	0.0095	stable
ΔlnX3	(0,0,2)	-2.174318	-2.717511	1.759237	0.0325	unstable
ΔlnX4	(C,T,0)	-5.635050	-4.571559	1.749323	0.0014	stable
ΔlnGDP	(C,T,1)	-3.947550	-4.616209	1.792742	0.0331	unstable
Δ^2lnX1	(0,0,3)	-3.995084	-2.740613	2.119394	0.0007	stable
Δ^2lnX2	(0,0,0)	-6.735716	-2.708094	1.510020	0.0000	stable
Δ^2lnX3	(0,0,1)	-5.714893	-2.717511	1.882827	0.0000	stable
Δ^2lnX4	(0,0,0)	-10.60409	-2.708094	2.450634	0.0000	stable
Δ^2lnGDP	(0,0,1)	-5.274793	-2.717511	1.987972	0.0000	stable

Note: In (C, T, K), C is the intercept term, T is the trend term, and K is the lag period. The intercept and trend terms are selected based on the characteristics of each sequence. Δ represents the first-order difference of the variable. Δ^2 represents the second-order difference of the variable.

According to the test results in Table 1, the original sequence has stationary sequences at the 1% significance level for LnGDP and LnX4, while the sequences for LnX1, LnX2, and LnX3 are non-stationary. The first-order differenced sequences are stationary time series at the 1% significance level for LnX1, LnX2 and LnX4, while the sequences for LnX3 and LnGDP are non-stationary. The second-order differenced sequences are stationary time series at the 1% significance level.

4.3. Model Building

As lnGDP, lnX1, lnX2, lnX3, and lnX4 are all second -order integrated series, satisfying the conditions for cointegration modeling, the following cointegration equation is established:

$$LnGDP=\beta_0+\beta_1 LnX1+\beta_2 LnX2+\beta_3 LnX3+\beta_4 LnX4+\varepsilon t$$

Where β_0 represents the constant term, β_1, β_2, β_3, β_4, and β_5 represent the estimated parameters, LnGDP represents the logarithm of Guangdong Province's GDP, LnX1, LnX2, LnX3, and LnX4 represent the logarithm of Guangdong Province's consumption of raw coal, oil products, electricity, and other energy sources, respectively, and εt represents the random disturbance term.

4.4. E-G Cointegration Test

The E-G two-step method is used for cointegration test.

In the first step, the model parameters are estimated. The least squares estimation method is used to estimate the parameters of the model using time series data of GDP, raw coal, oil products, electricity, and other energy consumption in Guangdong Province from 2002 to 2021, as follows:

$$LnGDP=-3.24+0.05LnX1-0.45LnX2+1.61LnX3+0.28LnX4$$

$$T = \quad (-1.79) \quad (0.19) \quad (-1.44) \quad (3.88) \quad (0.88)$$

R^2=0.978, F=169.32, DW=1.026, N=20.

Step 2: Conduct a stationary test on the residual sequence. Extract the residual sequence, denoted as e, from the above equation. The results of the ADF unit root test on the residual sequence e are shown in Table 2.

Table 2. *ADF unit root test results of residual e.*

Test variable	Inspection form	ADF statistics	5% significance level threshold	D.W value	P value	conclusion
e	(0,0,0)	-2.6095	-1.9601	1.8340	0.0121	stable

According to Table 2, the ADF test statistic is less than the critical value at the 5% significance level, and the corresponding p-value is less than 5%. Therefore, at the 5% significance level, the residual sequence e is stationary, indicating a long-term stable relationship between the explanatory variable LnGDP and the explanatory variables LnX1, LnX2, LnX3, and LnX4. Thus, the cointegration test is passed.

4.5. Multicollinearity Test and Correction

As shown in the above equation, the T statistics for LnX1, LnX2, and LnX4 are 0.19, -1.44, and 0.88, respectively. Their absolute values are all less than 2, indicating that the estimated cointegration model may suffer from multicollinearity.

To eliminate the multicollinearity in the cointegration model, we use stepwise regression. The results are shown in Table 3.

Table 3. *Results of step-up regression test.*

variable	C	lnX3	lnX1	lnX2	lnX4	adjusted R^2
lnX3	-5.193	1.696				0.970710
(T)	(-8.2)	(25.1)				
lnX3, lnX1	-5.130	1.698	-0.0104			0.968996
(T)	(-4.6)	(22.7)	(-0.07)			
lnX3, lnX2	-4.007	1.878		-0.346		0.972598
(T)	(-4.0)	(13.6)		(-1.5)		
lnX3, lnX2, lnX4	-2.997	1.551		-0.415	0.316	0.974209
(T)	(-2.5)	(5.9)		(-1.8)	(1.4)	

Four simple linear regression models were constructed with LnGDP as the dependent variable and LnX1, LnX2, LnX3, and LnX4 as the independent variables, resulting in R^2 values of 0.134157, 0.709416, 0.972252, and 0.931286, respectively. The equation with the highest R^2 value was selected as the base equation, which is LnGDP=f(LnX3).

By adding an explanatory variable LnX1 to the basic equation, the model becomes a bivariate linear regression model LnGDP=f(LnX3, LnX1). However, the adjusted R^2 decreased from 0.970710 to 0.968996, indicating a worse fit. Additionally, the T-statistic for the explanatory variable LnX1 was -0.07, indicating that it failed to pass the T-test. Therefore, LnX1 was removed from the model.

We added an explanatory variable LnX2 to the basic equation, and the model became a bivariate linear regression model LnGDP=f(LnX3, LnX2). Although the adjusted R^2 increased slightly from 0.970710 to 0.972598, the T-statistic for LnX2 was -1.5, indicating that it did not pass the T-test. However, we decided to keep the explanatory variable LnX2 for the time being.

Adding explanatory variable LnX4 to the binary linear regression model LnGDP=f(LnX3, LnX2) results in a ternary linear regression model LnGDP=f(LnX3, LnX2, LnX4). The adjusted R^2 increases slightly from 0.972598 to 0.974209. The T statistics for LnX2 and LnX4 are -1.8 and 1.4, respectively, and both absolute values are less than 2, indicating that they do not pass the significance test for variables at the 5% level. However, the explanatory variable LnX4 is temporarily retained, allowing the model to have partial multicollinearity.

The regression model contains partial multicollinearity:

$$LnGDP= -2.997-0.415LnX2+1.551LnX3+0.316LnX4$$

$$T = \quad (-2.49) \quad (-1.81) \quad (5.88) \quad (1.44)$$

$$R^2=0.978, F=240.231, DW=1.037, N=20.$$

4.6. Testing and Correction for Sequence Dependence

According to the LM test, as shown in Table 4, at a significance level of 5%, the model exhibits significant first-order autocorrelation but not second-order autocorrelation. Therefore, the model has maximum first-order autocorrelation at a significance level of 5%.

Table 4. *Results of LM test.*

Obs*R-squared	5.268800	Prob.Chi-Square(1)	0.0217
Obs*R-squared	5.273017	Prob.Chi-Square(2)	0.0716

Applying the generalized difference method to eliminate model autocorrelation yields the following results:

$$LnGDP=-0.59+0.12LnX2+0.70LnX3+0.47LnX4+0.96AR(1)$$

$$T = \quad (-0.27) \quad (0.59) \quad (3.82) \quad (2.35) \quad (7.94)$$

$$R^2=0.992415, F=366.3607, DW=1.624983, N=20.$$

In the above mode, the T statistics for C and lnX2 are -0.27 and 0.59, respectively, indicating that the variables are not significant. Therefore, we remove C and lnX2 to obtain a more optimized model.

$$LnGDP=0.698LnX3+0.507LnX4+0.963AR(1)$$

$$T = \quad (6.55) \quad (4.08) \quad (9.42)$$

$$R^2=0.992, F=26.946, DW=1.819, N=20.$$

In the abov model, F=26.946 indicates that the model is significant overall. The T statistics for LnX3, LnX4, and AR(1) are 6.55, 4.08, and 9.42, respectively, and their absolute values are greater than 2, indicating that they pass the significance test for variables and there is no longer multicollinearity. Meanwhile, DW=1.819, which is close to 2, indicating that there is no serial correlation. R^2=0.992 indicates that the model has an explanatory power of 99.2%. All of these indicate that this model is the optimal model.

5. Conclude the sentence

5.1. Conclusion

The following conclusions can be drawn from the optimal model:

(1) The logarithm of the explanatory variables, coal consumption (LnX1) and oil consumption (LnX2), have no significant effect on the logarithm of the explained variable, Guangdong GDP (LnGDP), at the 5% significance level.

(2) The logarithm of the explanatory variables, electricity consumption (LnX3) and other energy consumption (LnX4), have a significant effect on the logarithm of the explained variable, Guangdong GDP (LnGDP), at the 5% significance level. On average, a 1% increase in electricity consumption and other energy consumption leads to a 0.698% and 0.507% increase in Guangdong GDP, respectively.

(3) Although the logarithm of the explanatory variables, coal consumption (LnX1) and oil consumption (LnX2), have no significant effect on the logarithm of the explained variable, Guangdong GDP (LnGDP), in the current period, they have a significant positive effect with a one-year lag.

5.2. Policy Recommendations

Based on the above conclusions, the following policy recommendations are proposed:

Firstly, it is necessary to ensure the power supply in Guangdong Province, as a 1% increase in electricity consumption will lead to a nearly 0.7% increase in Guangdong's GDP, while a 1% decrease in electricity consumption will result in a nearly 0.7% decrease in Guangdong's GDP.

Secondly, there should be a strong focus on developing other energy sources, as a 1% increase in other energy consumption will lead to a nearly 0.51% increase in Guangdong's GDP, while a 1% decrease in other energy consumption will result in a nearly 0.51% decrease in Guangdong's GDP.

Finally, the supply of coal and oil products to Guangdong Province should be moderately guaranteed, as they have a one-year lag effect and cannot be ignored.

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