Analysis of factors affecting long-term coal demand in China
Error correction model based on co-integration

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Abstract. This paper studies the long-term equilibrium relationship of coal in China from the perspective of energy structure and economic structure by using co-integration technology, data of China from 1980 to 2018 are selected in this paper and estimates the long-term income elasticity, price elasticity, and the elasticity of economic structure and cross-price elasticity with natural gas; It simulates the evolution of long-term coal demand of various explanatory variables at different growth rates and gives policy choices. The results of the study indicate that the demand for coal is very sensitive to the change of economic structure and the adjustment of economic structure will greatly restrain the demand for coal.; The change of producer price has little influence on the change of coal demand; Considering the long-term course of economic development, the impact of natural gas consumption on coal demand is increasing.

1. Introduction
As one of China's main energy sources, coal is an important material foundation for China's economic development, accounting for about 60-70% of primary energy consumption and energy production. As a major energy consumer, China's energy consumption has risen sharply due to the rapid economic growth, and the contradiction between the supply and demand of energy has become increasingly prominent. However, with the reform of China's economic structure and energy structure, especially due to climate warming, natural gas prices plummeting and the role of renewable energy substitution, the coal demand has declined in some extent. According to the comprehensive energy review report released by the International Energy Agency (IEA) in 2020, China's coal demand is expected to decline by 5% in 2020.Therefore, how to quantitatively determine the impact of changes in China's economic structure and energy structure on coal demand has a crucial role.

In terms of resource economy theory, the coal as non-renewable resources, contrary to the common goods, even under the condition of perfect competition, the price of non-renewable resources and its marginal cost are also different. Therefore, most studies use econometric models to estimate the elasticity of energy demand and study the energy demand of a country. The measurement methods adopted by foreign literature on energy demand research mainly include: single-equation regression model (Brown, 1993; Gately and Rapport, 1998; Brown and Phillips, 1991); Panel data model (Pin Dyck, 1980; Lemuel,
Dynamic factor demand model (Hogan, 1989; Watkins, 1991; Fengyun, 2000); co-integration and error correction models. Among them, the co-integration and error correction models are most widely used. The main reason is that the traditional measurement model is based on the premise that the time series is stationary. If the time series is not stationary or contains a time trend term, the residual error of the model may also be non-stationary, which makes the statistics related to the residual lose their efficacy, resulting in the spurious regression problem in the regression of sample data, resulting in a large deviation in the estimation results. For the non-stationary time series (unit root variable), the traditional method is to obtain the stationary series by first difference and then model. However, the economic meaning of the variables after the first difference is not the same as the original sequence, and the sample size will be lost in some extent. The basic idea of co-integration is that if multiple unit root sequences have a common random trend, appropriate linear combinations of these variables can be made to eliminate the random trend, thus obtaining a stable time series and ensuring the original economic meaning of the variables.

Literature research about energy demand of China mainly includes: Xin etc. (2019) predicted China's total energy consumption demand in 2025 by using the elasticity coefficient method. Suo et al. (2019) predicted the coal consumption in Shanxi from 2017 to 2025 through a dynamic unbiased Markov structural prediction model; Zhang et al. (2019) believe that the pattern of supply and demand is the basic factor that affects prices, and policy factors work by affecting the balance of supply and demand. Guo (2018) takes the steel industry as the main demand analysis object to study the trend and sustainability of China's coking coal demand. Zou etc. (2018) used a new hybrid optimization algorithm, namely the adaptive bat algorithm based on exponential annealing (ABA-ESA algorithm), to predict China's coal demand from 2020 to 2030. Lin etc. (2007) used co-integration technology to study the long-term equilibrium relationship of China's coal demand.

Coal has been a major primary energy source for China, accounting for more than 70 percent of total energy consumption from 1978 to the mid-1990s. According to information released by the National Bureau of Statistics, as of the end of 2018, China's coal consumption accounted for 59% of total energy consumption, an increase of 3.7% compared to 2017. Therefore, for a long period of time in the future, coal as main energy consumption will not change in China, and along with the development of China's strong economic momentum, and the rise of urbanization will be further pull coal demand, therefore, for China's coal demand is crucial for modeling and forecasting.

This paper uses the co-integration model to study China's coal demand. Referring to previous literature, this paper introduces variables reflecting changes in economic structure and energy structure into the co-integration system under the price mechanism, and conducts an empirical study on the relationship between Coal consumption and changes in economic structure and energy structure in China by using VECM model, impulse response and variance decomposition technology.

2. Variable selection, data and co-integration test

The principles of variable filtering in this article are as follows: (1) Theoretical principles. Based on economic theory, this paper guarantees that the economic meaning of variables is significant. (2) Principle of representation. This article tries to choose a strong and representative variable; (3) Principles of data availability. Variables should have accurate statistics and be available in a timely manner. In general, national income and coal prices are the main factors of the coal demand. At the same time, as China is in the transition period of economic development, the changes of economic structure and energy structure also have a greater impact on coal demand. Therefore, the coal demand system in this paper includes five variables: $M_t$, $Y_t$, $P_t$, $T_t$, $E_t$. Among them, $M_t$ represents the coal demand in the Tth year; $Y_t$ represents GDP in the Tth year, $P_t$ represents producer price index in the Tth year. $T_t$ represents the consumption of natural gas in the Tth year, which reflects the change of energy structure. $E_t$ indicates the contribution rate of the secondary industry to GDP, which reflects the change of economic structure. The sample interval is from 1980 to 2018. Data are collected from China Economic Network, China Statistical Energy Yearbook, China Statistical Yearbook and China Coal Economic Network, and some of the data are calculated.

In this paper, the Johnson’s method is used to estimate co-integration vectors. In order to eliminate the influence of heteroscedastic-variance and variable unit, the natural logarithm of each variable was
taken in this paper, denoted as $LM_t$, $LY_t$, $LP_t$, $LT_t$, $LE_t$, respectively, and the linear relationship between them was the elasticity coefficient. First, the stationarity of the sequence is tested.

2.1. Unit root test

Common unit root test methods include ADF test, PP test and KPSS test. When the sample size is not big or close to the real model of unit root, ADF test and PP test efficiency is low (the first II mistake is a big probability), therefore, Kwiatkowski, Phillips, Schmidt and Shin (1992) proposed the KPSS test, the test of sample has good efficacy, KPSS test of the null hypothesis for $H_0$: smooth time series, this article USES the KPSS test results for determining stability. The unit root test is shown in Table 1. The test results show that the five time series are all first-order integral.

| variable | Horizontal statistic | First order difference statistics |
|----------|----------------------|-----------------------------------|
|          | ADF                  | KPSS    | PP      | ADF                  | KPSS    | PP      |
| $LM_t$   | -1.451               | 0.187** | -1.946  | -4.825***            | 0.103   | -4.939**|
| $LY_t$   | -0.553               | 0.151** | -1.436  | -3.146**             | 0.078   | -3.308**|
| $LP_t$   | -3.082               | 0.106** | -3.814  | -7.630***            | 0.030   | -7.983**|
| $LE_t$   | -3.622               | 0.570** | -3.090  | -8.341***            | 0.031   | -8.264**|
| $LT_t$   | -2.532               | 0.503***| -2.078  | -3.113**             | 0.165   | -3.097**|

Note: (1) *** (**; *) indicates at 1% (5%; 10%) reject the null hypothesis at the level; (2) Trend hypothesis: intercept term and trend term are selected in horizontal sequence, and the first difference does not include intercept term and trend term. (3) KPSS test is contrary to the null hypothesis of ADF and PP test.

2.2. Co-integration relationship test: Determination of long-term relationship

Johansen co-integration relationship test statistics mainly include Trace statistics and Max-Eigen statistics. Both use MLE to estimate VECM models. The difference is as follows: the null hypothesis of Trace statistics is that there is a co-integration relationship of $R$ individuals, while the alternative hypothesis is that there is a co-integration relationship of $K$ individuals. The null hypothesis of the Max-Eigen statistic is that there is $r$ individual co-integration relationship, and the alternative hypothesis is $R+1$ individual co-integration relationship.

| The null hypothesis for the number of co-integration vectors | Max - Eigen statistics | The 5% threshold | The Trace statistic | The 5% threshold |
|------------------------------------------------------------|------------------------|------------------|--------------------|------------------|
| None                                                       | 137.2522**             | 77.74            | 89.828             | 36.41            |
| Most one                                                   | 47.4242**              | 54.64            | 27.0936            | 30.33            |
| Most two                                                   | 20.3306                | 34.55            | 12.3703            | 23.78            |
| Most three                                                 | 7.9603                 | 18.17            | 5.3449             | 16.87            |
| Most four                                                  | 2.6154                 | 3.74             | 2.6154             | 3.74             |

Note: (1) ** means to reject the null hypothesis under the significance of 5%; (2) Trend hypothesis: There is a linear deterministic trend in time series data, and the co-integration equation has only intercept terms; (3) Lag interval: 1 to 1.

The co-integration test results in Table 2 show that, according to the max-Eigen statistics, there is only a unique co-integration relationship:
(4.07) (-1.84) (-5.56) (-7.34)

Equation (1) reflects the long-term equilibrium relationship between China's coal demand from 1980 to 2018, with T statistic in brackets and coefficient symbols as expected. Therefore, it can be concluded that the long-term income elasticity of China's coal demand since the reform and opening up is -0.39, which indicates the fundamental support for the rapid growth of national income and the growth of coal demand. The long-term ex-factory price elasticity of coal is 0.74, which is less than 1, indicating that coal is a necessity for economic development. The cross-price elasticity of coal and natural gas demand is 0.93, close to 1, indicating that in the long-term economic development, the two have strong substitution, which is consistent with economic theory and production experience. The long-term elasticity of the economic structure is 1.28, indicating that a rise in the proportion of secondary output in the long run will lead to a more substantial increase in coal demand.

2.3. Error correction model

Table 3 shows the error correction modeled (LM), D (LY), D (LP), D (LT) and D (LE) error correction coefficient T value were observed, and only two items were significant. This suggests that coal demand in the short term is adjusted mainly by the significant error correction coefficients D (LT) and D (LE).

|            | D(LM)  | D(LY)  | D(LP)  | D(LT)  | D(LE)  |
|------------|--------|--------|--------|--------|--------|
| **EC**     | 0.0116 | 0.0094 | 0.0861 | 0.0353 | 0.348  |
|            | (0.0258)| (0.0066)| (0.0364)| (0.0139)| (0.118) |
| **D(LM)-1**| 0.147  | 0.0512 | -0.136 | 0.130  | 1.016  |
|            | (0.194 )| (0.0500)| (0.273)| (0.105)| (0.888) |
| **D(LY)-1**| 1.201  | 0.905**| 4.180**| 1.466**| 9.531  |
|            | (1.375)| (0.355)| (1.939)| (0.742)| (6.298)|
| **D(LP)-1**| -0.0580| -0.0328| -0.277*| -0.0199| -0.354 |
|            | (0.117)| (0.0303)| (0.165)| (0.0633)| (0.537)|
| **D(LT)-1**| 0.0127 | -0.0776| -0.222 | 0.628***| -2.425***|
|            | (0.185)| (0.0477)| (0.261)| (0.0999)| (0.848)|
| **D(LE)-1**| -0.00500| 0.0161**| 0.0819**| 0.0242 | 0.231* |
|            | (0.0284)| (0.00733)| (0.0401)| (0.0153)| (0.130)|
| **C**      | -0.0427| 0.0333 | -0.170 | -0.0281| 0.0453 |
|            | (0.0785)| (0.0203)| (0.111)| (0.0424)| (0.360)|
| **R-squared**| 0.3994| 0.9669| 0.2784| 0.8836| 0.4514 |
| **JB test**| [2.548] | [3.537] | [1.132] | [1.536] | [1.718] |
| **BG test**| [0.5923]| [-0.3560]| [0.4097]| [0.4162]| [0.4165]|
| **WH test**| [3.4997]| [4.3349]| [2.7491]| [2.0458]| [3.6484]|
| **RESET test**| [0.0745]| [0.0192]| [0.1051]| [0.0402]| [0.3411]|
2.4. Long-term coal demand forecast of China
We will simulate the long-term equilibrium demand for coal in China in 2019-2028. The target trend of each variable is assumed to be the average annual GDP growth rate of 7%, the producer price growth rate of coal industry of 3%, the consumption growth rate of natural gas of 1%, the growth rate of economic structure variable remains unchanged, and the target simulation result is obtained. Then, we simulate the evolution path of China's coal demand under different GDP growth rates, and the simulation results are shown in Table 4.

The simulation results show that under the target trend assumption, the coal consumption will reach about 4.23 billion tons in 2028, indicating that under the current energy consumption structure, maintaining the high economic growth rate and the existing economic structure will rely heavily on coal. The simulation results of different GDP growth rates show that the 5.5% GDP growth rate makes China's coal demand forecast in 2028 4.47 billion tons, 240 million tons more than the target. The 6.5% GDP growth rate gives China a projected coal demand of 4.31 billion tons in 2028, 0.8 billion tons more than the target. The 7.5% GDP growth rate puts China's coal demand forecast for 2028 at 4.15 billion tones, 0.7 billion tones short of the target.

Table 4. Long-term Coal demand forecast in China (unit: 10,000 tons).

| Year | Long-term demand forecast results | Simulate different GDP growth rates | 5.5% of the GDP growth rate | 6.5% of the GDP growth rate | 7.5% of the GDP growth rate |
|------|----------------------------------|-------------------------------------|-----------------------------|-----------------------------|-----------------------------|
| 2019 | 405330.33                        | 407568.23                          | 406071.43                   | 404594.04                   |
| 2020 | 407256.34                        | 411765.81                          | 408746.94                   | 405778.10                   |
| 2021 | 409191.50                        | 416006.63                          | 411440.07                   | 406965.62                   |
| 2022 | 411135.86                        | 420291.12                          | 414150.95                   | 408156.62                   |
| 2023 | 413089.45                        | 424619.74                          | 416879.69                   | 409351.11                   |
| 2024 | 415052.33                        | 428992.94                          | 419626.41                   | 410549.09                   |
| 2025 | 417024.54                        | 433411.18                          | 422391.23                   | 411750.58                   |
| 2026 | 419006.11                        | 437874.92                          | 425174.27                   | 412955.58                   |
| 2027 | 420997.11                        | 442384.64                          | 427975.64                   | 414164.11                   |
| 2028 | 422997.56                        | 446940.80                          | 430795.47                   | 415376.18                   |

Note: Target trend hypothesis: 7%GDP growth rate; 0% economic structure variable growth rate; the growth rate of producer price for coal; 1% growth rate of natural gas consumption.

As forecasts are based on historical data, future changes in energy consumption structure, fluctuations in income growth, changes in industrial structure and uncertainties in the energy market as China's economy becomes more open will all play a role. However, the co-integration relationship reflects a long-term equilibrium relationship, which still has a strong reference value in the long run.

3. Coal demand simulation analysis
The paper makes a further simulation analysis of coal demand. We found that a lower GDP growth rate can reduce coal demand according to the above demand model. But maintaining a high economic growth rate (about 7%) is the guarantee of China's social development and employment. Therefore, it should not be included in China's policy simulation analysis. On the contrary, the other three variables are all influenced by government departments through industrial policies and price guidance policies, so they can all become policy tools to inhibit coal demand to some extent. On the basis of the target hypothesis, we change the changeable range of three variables other than GDP one by one to simulate the evolution route of coal demand in the future. The simulation results are shown in Table 5.
Table 5. Long-term Coal Demand Simulation analysis in China (unit: 100 million tons).

| Year | Equilibrium demand forecast results | Simulate the growth rate of producer price of coal industry | Simulate growth rate of natural gas consumption | Simulate the rate of change of economic structure |
|------|-----------------------------------|----------------------------------------------------------|-----------------------------------------------|-----------------------------------------------|
|      |                                   | -1% 2% 5%                                                 | -1% 2% 3%                                     | -0.5% -0.1% 0.1%                              |
| 2019 | 40.53                             | 39.36 40.24 41.11                                         | 39.21 40.32 40.68                            | 39.69 39.90 40.00                             |
| 2020 | 40.73                             | 38.41 40.14 41.90                                         | 38.12 40.29 41.03                            | 39.06 39.46 39.66                             |
| 2021 | 40.92                             | 37.47 40.04 42.70                                         | 37.05 40.27 41.38                            | 38.43 39.03 39.33                             |
| 2022 | 41.11                             | 36.57 39.94 43.52                                         | 36.01 40.24 41.73                            | 37.81 38.60 38.99                             |
| 2023 | 41.31                             | 35.68 39.84 44.36                                         | 35.01 40.22 42.09                            | 37.21 38.17 38.66                             |
| 2024 | 41.51                             | 34.81 39.75 45.20                                         | 34.03 40.19 42.44                            | 36.61 37.75 38.34                             |
| 2025 | 41.70                             | 33.97 39.65 46.07                                         | 33.08 40.17 42.80                            | 36.02 37.34 38.01                             |
| 2026 | 41.90                             | 33.14 39.55 46.95                                         | 32.15 40.15 43.17                            | 35.44 36.93 37.69                             |
| 2027 | 42.10                             | 32.34 39.45 47.85                                         | 31.25 40.12 43.54                            | 34.87 36.52 37.37                             |
| 2028 | 42.30                             | 31.55 39.35 48.77                                         | 30.38 40.10 43.91                            | 34.31 36.12 37.06                             |

The main conclusions of the simulation analysis are as follows: The simulation results of the ex-factory price of coal indicate that the change of coal price affects the future coal demand. The -1% coal price growth rate will bring coal demand to 3.155 billion tons in 2028, which is 1.075 billion tons less than the target forecast; 295 million tons less than the target forecast; If the coal price growth rate reaches 5%, the predicted value of coal demand in 2028 will reach 4.877 billion tons, which is 647 million tons more than the target forecast. The forecast is premised on keeping other variables unchanged. When the price of coal falls while the price of other energy remains unchanged, the substitution effect of coal for other energy may occur. However, since China's coal-based energy structure will exist for a long time, this effect will not be too great. The simulation results of natural gas consumption indicate that the change of natural gas consumption affects the future coal demand. The -1% natural gas consumption growth rate will bring coal demand to 3.038 billion tons in 2028, which is 1.192 billion tons less than the target forecast; The 2% natural gas consumption growth rate will bring coal demand to 4.01 billion tons in 2028, which is 120 million tons less than the target forecast; The 3% natural gas consumption growth rate will bring coal demand to 4.391 billion tons in 2028, which is 161 million tons less than the target forecast; Although natural gas is an important substitute resource of coal, and the rapid development of new energy in China in recent years has had a certain impact on coal demand, coal resources are still the most important part of China’s energy structure. Without effective adjustment, even if the demand for other alternatives and complementary products has increased, the impact on coal demand will not be great, so China's energy structure adjustment still has a long way to go. The simulation results of the economic structure adjustment show that -0.5% of the economic structure adjustment will bring coal demand to 3.431 billion tons in 2028, which is 799 million tons less than the target forecast; The 0.1% economic structure adjustment will bring coal demand to 3.612 billion tons in 2028, which is 618 million tons less than the target forecast. The 0.2% economic structure adjustment will bring coal demand to 3.706 billion tons in 2028, which is 524 million tons less than the target forecast. The forecast results show that the coal demand is very sensitive to the adjustment of the economic structure. The main reason is that the heavy industry represented by coal occupies an excessive proportion in the Chinese economic structure. The development of heavy industry mainly depends on energy consumption, but it also needs to pay a huge environmental cost. Therefore, in the long run, it is an effective policy orientation to reduce China's excessive reliance on coal and reduce the demand for coal in the future by adjusting China's industrial structure to light industry and tertiary industry with low energy consumption and high added value, improving energy utilization efficiency and developing renewable energy.
4. Conclusions and policy recommendations
The above model mainly forecasts and analyzes the long-term demand of coal in China. The main conclusions of the model include:

(A) China's rapid economic growth is the main reason for the increase in coal demand. This paper estimates the long-term equilibrium demand for coal in China in 2028, at 4.23 billion tons, which is higher than other forecasts. It shows that under the existing energy structure, maintaining rapid economic growth and keeping the economic structure unchanged will rely heavily on coal resources.

(B) Even a small economic structural adjustment will have a great inhibitory effect on coal demand. It is difficult to adjust the economic structure in a short period of time. Therefore, in the medium and long term, it is an effective policy orientation to reduce China's excessive reliance on coal and reduce the demand for coal in the future by adjusting China's industrial structure to light industry and tertiary industry with low energy consumption and high added value, improving energy utilization efficiency and developing renewable energy.

(C) The large increase in coal demand by 2028 is expected to continue to put pressure on coal prices, which will eventually lead to the possibility of subsequent industry cost increases and inflation. The government should try to reduce the pressure of rising coal prices.

The suppression of excessive demand for coal can be guided by industrial policies and price guidance policies. In the short term, the fine-tuning of the economic structure ratio and the appropriate guidance of price variables can suppress the excessive growth of coal demand, and at the same time prevent the cost-driven inflation problems that may be caused by excessive coal prices; The medium and long-term policy is to adjust the coal resource tax, realize industrial policy adjustment, develop alternative energy, clean energy, improve energy efficiency to reduce dependence on coal, and increase resource allocation based on the introduction of price evasion measures such as coal futures contracts. Effectiveness. The government encourages the development of a circular economy and can also reduce energy consumption per unit of product, thereby reducing coal demand.

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