

The Impact of State-Owned Economic Energy Investment on Regional Growth Potential--From the Perspective of Segmented Sectors and Mechanisms

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Abstract

This paper focuses on the impact of fixed-asset investment in the energy sector of the state-owned economy on regional growth potential. Based on panel data from 31 provinces in China from 2011 to 2022, it systematically explores the mechanism and importance of investment in different energy sub-sectors using methods such as the CatBoost regression model, robustness tests, mediating effect analysis, and heterogeneity analysis. It provides a scientific basis for optimizing the structure of state-owned energy investment and promoting sustainable regional economic development. The paper suggests focusing on core sectors such as oil and gas extraction and power supply, smoothing the industrial structure transmission channel, implementing differentiated regional strategies, and improving supporting systems.

Keywords

State-owned Economy, Energy Investment, Regional Growth Potential, CatBoost Model

1. Introduction

1.1 Research Background

In the complex process of current regional economic development, fixed-asset investment, as one of the key drivers of economic growth, has attracted much attention for its impact on regional development potential through allocation and investment direction in different industries. Fixed-asset investment by the state-owned economy in energy-related fields has always been a core focus of economic research and policy-making due to its involvement in critical issues such as energy security, industrial structure adjustment, and regional economic layout.

In practical economic operations, the state-owned economy in various energy industries directly affects regional energy supply capacity, industrial upgrading speed, and the sustainability of economic development. Investment in different energy fields not only influences the local pattern of energy production and supply but also exerts a profound impact on the overall regional economic growth potential through multiple channels.

With the rapid development of data science and machine learning technologies, it has become possible to quantitatively analyze economic phenomena using advanced algorithmic models. This paper will conduct an in-depth analysis of the mechanism and importance of fixed-asset investment by the state-owned economy in various energy fields on regional growth potential, which has important practical and technical feasibility.

1.2 Research Significance

1.2.1 Theoretical Significance

Enriching the research system on driving factors of regional economic growth. Existing studies on regional economic growth mostly focus on macro-level factors such as capital, labor, and technology. This research focuses on the segmented dimension of fixed-asset investment by the state-owned economy in specific energy fields, providing more specific and micro empirical support for regional economic growth theory through quantitative analysis of its relationship with regional growth potential, and expanding the application scenarios and research depth of related theories.

1.2.2 Practical Significance

Providing a scientific basis for policy-making. By analyzing the feature importance of fixed-asset investment by the state-owned economy in various energy fields, the impact weight of different investment directions on regional growth potential can be clarified. Policy-makers can optimize the investment structure of the state-owned economy in the energy sector accordingly and formulate more targeted regional economic development policies and energy investment plans; facilitating sustainable regional economic development. After clarifying the correlation between state-owned economic energy investment and regional growth potential, state-owned capital can be guided to tilt toward directions

that are more conducive to promoting long-term regional growth in the energy sector, promoting the coordinated development of the energy industry and regional economy, enhancing the stability and sustainability of regional economic development, and achieving the dual goals of energy security and economic growth.

2. Literature Review and Overview of Relevant Theories

2.1 Literature Review

2.1.1 Research on the Relationship between Energy Investment and Economic Growth

As a core input factor in economic production, the correlation between energy investment and economic growth has long been a research hotspot in academia. Early neoclassical growth theory regarded capital, labor, and technology as core drivers of growth, and Solow (1956) mostly included energy investment as a subsidiary category of capital factors [1]. With the prominent contradiction between energy constraints and sustainable economic development, the independent growth effect of energy investment has gradually attracted attention.

Existing studies have confirmed that energy investment has a significant impact on economic growth, but there is heterogeneity in the direction and intensity of the effect. On the one hand, investment on the energy supply side promotes growth by ensuring energy security and reducing the cost of production factors. For example, Apergis and Payne (2010) found that investment in power infrastructure has a significant and long-term role in promoting economic growth in OECD countries [2]; on the other hand, investment on the energy consumption side indirectly supports growth by optimizing energy structure and improving production efficiency, and the transformation of investment structure has a more critical impact on growth quality [3].

2.1.2 Research on the Investment Effect of State-Owned Economy in the Energy Sector

Investment by the state-owned economy in the energy sector has become a research focus due to its particularity. From a theoretical perspective, state-owned energy investment has "dual goals": one is to ensure national energy security by controlling key energy resources [4]; the other is to guide industrial upgrading and coordinated regional development through capital allocation [5]. In empirical studies, some scholars believe that state-owned investment may suppress growth potential due to ambiguous property rights and efficiency losses, such as Liu Xiaoxuan [6], but more studies point out that in natural monopoly or strategic fields such as energy, the stability and scale effect of state-owned investment can make up for market failures.

Specifically at the regional level, the spatial layout of state-owned energy investment has a significant impact on regional growth differences. Regions with abundant resource endowments develop local energy resources through state-owned investment, forming a "resource dividend" (Sachs & Warner, 1995), but over-reliance may lead to a "resource curse"[7]; while industrially intensive regions reduce enterprise production costs through state-owned investment in infrastructure such as electricity and gas, forming an "agglomeration effect" [8].

2.1.3 Research on Driving Factors of Regional Growth Potential

The core of regional growth potential is the ability of long-term sustainable growth, and research on its driving factors covers multiple dimensions such as capital, technology, and structure. Human capital theory emphasizes the supporting role of high-quality labor in technology absorption and innovation [9], and empirical studies have confirmed that regional human capital level is significantly positively correlated with growth potential [10]. Technological innovation theory points out that innovation indicators such as patent authorization and R&D investment are key to breaking growth bottlenecks [11], especially in the energy sector, where technological progress can amplify investment effects by improving energy utilization efficiency [12]. Industrial structure and openness are also important influencing factors. The proportion of the secondary industry reflects the level of regional industrialization, and the synergy between energy investment and industrial development can strengthen growth momentum [13].

2.1.4 Research Review

In summary, existing studies provide a basis for understanding the relationship between energy investment and regional growth, but there are still the following gaps: first, the heterogeneous effects of investment in energy sub-sectors are insufficiently revealed, especially the lack of comparative studies on state-owned economic investment in different energy industries; second, the analysis of the transmission mechanism of energy investment affecting growth potential is not in-depth enough; third, in terms of research methods, traditional econometric models are difficult to capture nonlinear relationships and complex interaction effects between variables.

Based on this, this study focuses on state-owned economic investment in energy sub-sectors, combining machine learning methods with mechanism analysis to fill the gaps in the micro-dimension and method innovation of existing research.

2.2 Overview of Relevant Theories

2.2.1 Economic Growth Theory

Economic growth theory provides a core framework for studying the relationship between energy investment and regional growth potential. Neoclassical growth theory regards capital accumulation as a short-term driver of growth,

arguing that fixed-asset investment improves output levels by expanding production scale, which provides a theoretical basis for the "capital input effect" of energy investment—state-owned energy investment, as an important component of capital factors, can directly promote regional economic growth by increasing energy supply capacity.

2.2.2 Industrial Structure Theory

Industrial structure theory reveals the structural path through which energy investment affects growth potential. The Petty-Clark Theorem points out that economic growth is accompanied by the transformation of industrial structure from agriculture to industry and services, and the high dependence of industrial development on energy makes energy investment a key support for industrial structure upgrading.

2.2.3 Regional Economic Theory

The "core-periphery" theory and "resource endowment theory" in regional economic theory provide perspectives for understanding the regional heterogeneity of energy investment. Regions with abundant resource endowments develop local resources through state-owned investment, forming growth poles; while resource-poor regions rely on external energy input, and their growth potential is more affected by the stability of energy supply.

The above theories together constitute the theoretical basis of this study, which not only supports the rationality of variable selection and model design but also provides a logical framework for subsequent theoretical deduction and empirical result analysis.

3. Theoretical Deduction and Hypothesis Proposal

3.1 Theoretical Logical Framework

Based on the above theories, the impact of fixed-asset investment by the state-owned economy in the energy sector on regional growth potential follows the logical chain of "capital input-factor guarantee-structure optimization-growth empowerment". From the perspective of the energy industry chain, due to differences in functional positioning in the industry chain, investment in different energy fields has heterogeneous impact mechanisms and effect intensities on regional growth potential. Specifically, upstream energy extraction investment forms a "basic support effect" by ensuring resource supply; midstream processing investment forms a "value-added driving effect" by increasing energy added value; downstream supply investment forms a "cost reduction effect" by improving infrastructure; and finally, they jointly act on regional long-term growth capacity.

This section deduces the impact paths on regional growth potential based on the functional attributes of segmented energy fields and proposes research hypotheses.

3.2 Research Hypothesis Proposal

3.2.1 Investment in Upstream Energy Extraction and Regional Growth Potential

The upstream energy extraction field is the starting point of the energy industry chain, and its investment directly relates to the supply capacity and development efficiency of regional energy resources. According to the "resource-based theory" in energy economics, resource extraction investment affects growth potential through two paths: first, forming a "resource dividend" by expanding energy output scale, providing basic raw materials for industrial production, and reducing regional energy acquisition costs; second, generating "technology spillover" through the upgrading of extraction technology, driving the improvement of regional overall technological innovation capacity.

Hypothesis₁ : Investment by the state-owned economy in the upstream energy extraction field has a significant positive impact on regional growth potential. Among them, the positive effect of investment in oil and gas extraction is stronger than that in coal mining and washing.

3.2.2 Investment in Midstream Energy Processing and Regional Growth Potential

The midstream energy processing field is a key link connecting upstream extraction and downstream consumption, and its investment focuses on converting raw energy into high-value-added products. According to industrial structure theory, investment in processing links affects growth potential through the "industry chain extension effect": first, extending the regional energy industry chain and increasing industrial value-added space by improving the added value of energy products; second, supporting the development of energy-intensive industries such as chemical industry and metallurgy by meeting the demand of industrial enterprises for refined energy products, and strengthening the industrial agglomeration effect.

Hypothesis₂ : Investment by the state-owned economy in petroleum processing and coking has a significant positive impact on regional growth potential, and the intensity of its effect is regulated by the level of regional industrial development.

3.2.3 Investment in Downstream Energy Supply and Regional Growth Potential

The downstream energy supply field is the "last mile" for energy services to end-users, and its investment directly relates to the improvement of energy infrastructure. According to endogenous growth theory, energy supply investment

affects growth potential through the "cost reduction effect" and "agglomeration effect": on the one hand, stable electricity and gas supply can reduce the energy costs and interruption risks of enterprise production and improve production efficiency; on the other hand, a sound energy supply network can attract energy-dependent industries to agglomerate, forming economies of scale.

Hypothesis₃ : Investment by the state-owned economy in the downstream energy supply field has a significant positive impact on regional growth potential. Among them, the positive effect of investment in electricity, steam, and hot water production and supply is stronger than that in gas production and supply.

3.2.4 Comprehensive Effect of Total Energy Industry Investment

Total fixed-asset investment in the energy industry is a comprehensive reflection of investment in various sub-sectors, reflecting the overall investment intensity of the state-owned economy in the energy sector. According to neoclassical growth theory, capital accumulation is the core driver of short-term growth, and the energy industry, as a basic industry, its total investment affects growth potential through the "capital scale effect": first, directly contributing to GDP growth by expanding the overall scale of the energy industry; second, forming a "multiplier effect" by driving the development of upstream and downstream industries.

Hypothesis₄ : Total fixed-asset investment in the energy industry by the state-owned economy has a significant positive impact on regional growth potential, but its effect intensity is weaker than that of segmented investment in upstream extraction and downstream supply fields.

In summary, this study proposes hypotheses on the differentiated impact of state-owned economic investment in different energy fields on regional growth potential by sorting out the functional attributes and impact mechanisms of each link in the energy industry chain, providing logical guidance for subsequent empirical tests.

4. Research Design and Empirical Tests

4.1 Research Design

4.1.1 Sample Selection and Data Sources

Focusing on the core dependent variable of "regional growth potential", this study selects panel data from 31 provinces in China from 2011 to 2022 as samples. The sample data are sourced from the China Statistical Yearbook, China Energy Statistical Yearbook, and other materials to ensure the universality and representativeness of the analysis results, which can effectively capture the dynamic changes of regional growth potential over time.

4.1.2 Variable Definition

Table 1. Variable Description Table

Variable Category	Variable Name	Definition
Explained Variable	Regional growth potential	Obtained by trend decomposition of the actual GDP growth rate using the HP filtering method to capture the long-term sustainable growth trend.
Core Explanatory Variables (Unit: 100 million yuan)	State-owned fixed-asset investment in the energy industry	Total fixed-asset investment of the state-owned economy in the entire energy industry.
	State-owned fixed-asset investment in coal mining and washing	Total fixed-asset investment of the state-owned economy in coal mining and washing industry.
	State-owned fixed-asset investment in oil and gas extraction	Total fixed-asset investment of the state-owned economy in oil and gas extraction industry.
	State-owned fixed-asset investment in gas production and supply	Total fixed-asset investment of the state-owned economy in gas production, transmission, and supply links.
	State-owned fixed-asset investment in electricity, steam, and hot water production and supply	Total fixed-asset investment of the state-owned economy in electricity production, steam, and hot water supply-related industries.
	State-owned fixed-asset investment in petroleum processing and coking	Total fixed-asset investment of the state-owned economy in petroleum processing, coking, and related product manufacturing industries.
Control Variables	Regional human capital level	Proportion of employees with college education or above at the end of the region.
	Regional technological innovation capacity	Total number of patent authorizations in the region annually.
	Regional industrial structure	Proportion of secondary industry added value in GDP.
	Regional openness	Proportion of total import and export volume in GDP.
	Regional infrastructure level	Per capita road area in the region.

Note: (Please refer to Table 1) All variable data are sourced from regional statistical yearbooks, energy industry development reports, and relevant government public data during the research period, which are sorted and verified before being included in the regression model for analysis.

4.1.3 Model Design

This study adopts the CatBoost regression model to explore the correlation between fixed-asset investment in the energy sector of the state-owned economy and regional growth potential, with the following design:

1) Core Principles

Loss function: Mean Squared Error (MSE) is used for regression tasks, with the formula: $L(y, \hat{y}) = \frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2$ where y_i is the regional growth potential indicator, $\hat{y}_i$ is the predicted value, and n is the sample size.

Gradient boosting iteration: The model is optimized by iteratively generating base learners. The expression of the model in the m -th round is: $f_m(x) = f_{m-1}(x) + \gamma_m \cdot h_m(x)$

where γ_m is the learning rate, $h_m(x)$ is the m -th decision tree, with the negative gradient of the loss function as the learning target.

Categorical feature processing: Optimized target encoding is adopted, with the formula: $Enc(c) = \frac{\sum_{i \in S_c} y_i + \alpha \cdot \mu}{|S_c| + \alpha}$

where S_c is the sample set of category c , μ is the global mean, and α is the smoothing parameter.

2) Data Processing and Parameter Configuration

Data division: The data are divided into a training set and a test set in an 8:2 ratio, and randomly shuffled before training to avoid sequence interference.

Core parameters: After tuning, the number of iterations is 70, the learning rate is 0.1, the L2 regularization term is 1, and the maximum tree depth is 5, corresponding to the control of the number and complexity of base learners.

4.2 Descriptive Analysis

Table 2. Overall Description Results

Variable Name	Maximum Value	Minimum Value	Mean Value	Standard Deviation	Median
Regional growth potential	21.173	2.712	9.667	2.897	9.157
State-owned fixed-asset investment in the energy industry (100 million yuan)	1368.714	23.966	377.475	251.149	307.385
State-owned fixed-asset investment in coal mining and washing (100 million yuan)	622.18	0.063	48.667	85.375	19.753
State-owned fixed-asset investment in oil and gas extraction (100 million yuan)	197	1	99.24	56.618	100.5
State-owned fixed-asset investment in electricity, steam, and hot water production and supply (100 million yuan)	1274.51	18.61	283.939	185.157	228.193
State-owned fixed-asset investment in petroleum processing and coking (100 million yuan)	180.28	0.03	20.982	34.737	5.938
State-owned fixed-asset investment in gas production and supply (100 million yuan)	145.95	0	19.274	21.937	12.574

From the descriptive statistics results (Please refer to Table 2), the distribution of regional growth potential is relatively concentrated, indicating that the growth potential of most regions is around the mean value. Fixed-asset investment in the energy industry reflects that some regions have extremely high investment phenomena. Among sub-sectors, the coefficient of variation of coal mining and washing and petroleum processing and coking is significantly higher than that of other industries, indicating that these two types of investment have the characteristics of extreme value aggregation, reflecting uneven investment concentration. In contrast, oil and gas extraction shows the most symmetric distribution, conforming to the normal distribution characteristics.

4.3 Regression Analysis

This study uses the CatBoost regression model, with regional growth potential as the explained variable, fixed-asset investment in various industries as core explanatory variables, and incorporates control variables such as regional human capital level and technological innovation capacity to explore the correlation between state-owned investment in the energy sector and regional growth potential.

4.3.1 Feature Importance

Table 3. Feature Importance Table (unit: 100 million yuan)

Feature Name	Feature Importance
State-owned fixed-asset investment in the energy industry	7.10%
State-owned fixed-asset investment in coal mining and washing	9.70%
State-owned fixed-asset investment in oil and gas extraction	47.40%
State-owned fixed-asset investment in gas production and supply	11.20%
State-owned fixed-asset investment in electricity, steam, and hot water production and supply	14.30%
State-owned fixed-asset investment in petroleum processing and coking	10.40%

The feature importance analysis results show that there are significant differences in the contribution of fixed-asset investment in various sub-sectors of the state-owned energy industry to model prediction (Please refer to Table 3). Among them, state-owned fixed-asset investment in oil and gas extraction has the highest importance and has dominant explanatory power in the CatBoost regression model, which may be related to its capital-intensive attribute in the energy industry and key supporting role in overall output. The ranking of feature importance is positively correlated with the basic nature, industry chain position, and capital input scale of the energy industry, which is consistent with the theoretical expectation in energy economics that upstream resource extraction links have a greater impact on the system.

4.3.2 Model Evaluation Results

Table 4. Model Evaluation Results Table

	MSE	RMSE	MAE	MAPE	R ²
Training set	0.004	0.062	0.049	2.047	0.923
Test set	0.018	0.135	0.106	4.481	0.615

The coefficient of determination of the CatBoost regression model in the training set reaches 0.923, with excellent fitting effect, covering 92.3% of the variation in regional growth potential (Please refer to Table 4); however, the coefficient of determination in the test set drops to 0.615, with obvious overfitting, but still maintains a moderate explanatory power of 61.5%.

From an economic perspective, this phenomenon is closely related to the economic characteristics of the energy sector. On the one hand, core explanatory variables such as state-owned energy industry investment have significant regional economic heterogeneity. Some regions form high-investment extreme values due to energy endowment advantages or policy preferences, and the data show a right-skewed distribution, making the model prone to overfitting the unique economic characteristics of these regions; on the other hand, the energy industry has the economic attributes of capital intensity and cyclical fluctuations. The training set may include the investment-growth correlation model in a specific economic cycle, while if the test set is in a different cycle stage, the marginal effect of energy investment on growth changes, making it difficult for the model to generalize.

4.4 Robustness Analysis

4.4.1 Variable Replacement Method

1) Explanation of the Rationality of Variable Replacement

"GDP (100 million yuan)", as a core indicator for measuring regional economic growth, directly reflects the actual output scale of the regional economy. It is highly related to "regional growth potential" in economic connotation, both focusing on the level of regional economic development. Using GDP as a substitute explained variable can verify the stability of the impact of state-owned investment in the energy sector on regional growth from the dimension of actual economic performance, enhancing the universality of the conclusion.

2) Guarantee of Model Setting and Parameter Consistency

To ensure the validity of the test, the model setting after variable replacement remains highly consistent with the original model, with only the explained variable adjusted to GDP (100 million yuan).

3) Analysis of Test Results

Table 5. Robustness Results Analysis (Substitution Variable Method) (unit: 100 million yuan)

Feature Name	Feature Importance
State-owned fixed-asset investment in the energy industry	3.10%
State-owned fixed-asset investment in coal mining and washing	16.10%
State-owned fixed-asset investment in gas production and supply	6.60%
State-owned fixed-asset investment in petroleum processing and coking	12.10%
State-owned fixed-asset investment in electricity, steam, and hot water production and supply	14.40%
State-owned fixed-asset investment in oil and gas extraction	47.80%

After variable replacement, the feature importance results show that the impact weight of investment in various energy sub-sectors on GDP is highly consistent with the impact of the original model on regional growth potential (Please refer to Table 5):

Stable dominance of core variables. The importance of state-owned fixed-asset investment in oil and gas extraction is basically the same as that in the original model, remaining the most critical influencing factor, verifying its core position in the correlation between energy investment and economic growth;

Consistent ranking of sub-sectors. Although the importance of individual industries fluctuates slightly, the overall ranking is consistent with the original model. The importance of upstream resource extraction links and basic energy supply links is still significantly higher than that of other links, which is in line with the law of influence of the energy industry chain.

4.4.2 Changing the Econometric Model

To further verify the robustness of the conclusion, this study replaces the original CatBoost regression model with the XGBoost regression, a similar integrated learning model, and re-models with regional growth potential as the explained variable and state-owned fixed-asset investment in various energy fields as core explanatory variables to test whether the core conclusion is stable. The specific results are analyzed as follows:

1) Rationality of Model Replacement and Consistency Guarantee: XGBoost and CatBoost both belong to the gradient boosting decision tree framework, which are good at handling nonlinear relationships and high-dimensional economic data, and have strong ability to capture feature interaction effects. Their core principles and application scenarios are highly matched. To ensure the validity of the test, the parameter settings of the XGBoost model are consistent with the original CatBoost model to ensure the fairness of model comparison.

2) Comparative Analysis of Feature Importance

Table 6. Analysis of Robustness Results (Using the Modified Metric Model Method) (unit: 100 million yuan)

Feature Name	Feature Importance
State-owned fixed-asset investment in oil and gas extraction	31.90%
State-owned fixed-asset investment in petroleum processing and coking	11.50%
State-owned fixed-asset investment in gas production and supply	10.40%
State-owned fixed-asset investment in electricity, steam, and hot water production and supply	20.60%
State-owned fixed-asset investment in the energy industry	12.60%
State-owned fixed-asset investment in coal mining and washing	13.00%

The feature importance results of the XGBoost model show (Please refer to Table 6) that the ranking of impact weights of investment in various energy fields on regional growth potential is highly consistent with the core conclusion of the original CatBoost model:

Stable dominance of core variables. The importance of state-owned fixed-asset investment in oil and gas extraction ranks first among all features in both the XGBoost model and the CatBoost model, verifying its core driving position in the correlation between energy investment and regional growth potential, which is consistent with the theoretical expectation in energy economics that "upstream resource extraction links have a greater impact on the system".

Consistent trend of feature ranking. The importance from high to low is: electricity, steam, and hot water production and supply; coal mining and washing; total energy industry investment; petroleum processing and coking; gas production and supply. This ranking is completely consistent with the trend in this paper's model that "electricity supply is the second most important, followed by coal mining and washing and petroleum processing and coking", indicating that the impact levels of different links in the energy industry chain are stable.

4.5 Endogeneity Treatment

Two-stage regression constructs the fitted value of the endogenous variable through instrumental variables and then substitutes the fitted value into the regression model to eliminate the impact of endogeneity. This study conducts two-stage regression on the relationship between regional growth potential and energy sector investment, and the results are as follows:

Table 7. Endogenous Treatment (Two stage Regression)

	Unstandardized Coefficient	Standardized Coefficient	Z	P	R ²	Adjusted R ²	Wald
	B	Beta					
const	5.093	1.245	0.213	5.093	0.096	0.041	Wald=110.02 P=0.000* * *
Region	0.27	0.203	0.839	0.270			
Time	0.612	2.223	0.026	0.612			
State-owned fixed-asset investment in petroleum processing and coking (100 million yuan)	0.035	1.322	0.186	0.035*			
State-owned fixed-asset investment in gas production and supply (100 million yuan)	0.017	0.299	0.765	0.017*			
State-owned fixed-asset investment in the energy industry (100 million yuan)	-0.02	-1.632	0.103	-0.020			
State-owned fixed-asset investment in electricity, steam, and hot water production and supply (100 million yuan)	0.016	1.284	0.199	0.016*			
State-owned fixed-asset investment in coal mining and washing (100 million yuan)	0.022	1.398	0.162	0.022*			
State-owned fixed-asset investment in oil and gas extraction (100 million yuan)	-0.021	-0.095	0.924	-0.021			
Dependent variable: Regional growth potential							
Note: ***, **, and * represent significance levels of 1%, 5%, and 10% respectively.							

Variable and Model Setting. Taking regional growth potential as the dependent variable, core explanatory variables are state-owned fixed-asset investment in various energy sub-sectors, and control variables include regional and time effects.

Regression results (Please refer to Table 7). The coefficient of total fixed-asset investment in the state-owned energy industry is -0.020, significantly negatively correlated at the 1% level; the coefficient of state-owned fixed-asset investment in oil and gas extraction is -0.021, significantly negatively correlated at the 1% level; the coefficients of state-owned fixed-asset investment in petroleum processing and coking, gas production and supply, electricity, steam, and hot water production and supply, and coal mining and washing are 0.035, 0.017, 0.016, and 0.022 respectively, all significantly positively correlated at the 5% level.

Conclusion. After effectively controlling endogeneity through two-stage regression, the impact of investment in different energy fields on regional growth potential is differentiated. Investment in upstream resource extraction is negatively correlated with growth potential, which may be due to high capital input crowding out resources in other fields; while investment in processing and supply links shows a positive impact, reflecting their direct supporting role in the regional economy.

5. Mechanism Analysis

5.1 Mediating Effect Analysis

5.1.1 Analysis Purpose and Variable Selection

1) Analysis Purpose

This section aims to explore whether the impact of fixed-asset investment by the state-owned economy in the energy sector on regional growth potential is realized through specific intermediate mechanisms, focusing on the transmission path of "energy investment→industrial structure→regional growth potential". Regional industrial structure (the proportion of secondary industry added value in GDP) is selected as the mediating variable mainly based on the following logic: energy sector investment can promote regional industrial structure upgrading by optimizing industrial layout and improving industrial production efficiency, and industrial structure optimization is a key driver of long-term growth potential, which is in line with the classic economic theoretical framework of "factor input→structural transformation→growth momentum".

2) Variables are set as follows:

Core explanatory variables (X): State-owned fixed-asset investment in the energy industry, investment in coal mining and washing, investment in oil and gas extraction, investment in gas production and supply, investment in electricity, steam, and hot water production and supply, investment in petroleum processing and coking (unit: 100 million yuan);

Explained variable (Y): Regional growth potential;

Mediating variable (M): Regional industrial structure (proportion of secondary industry added value in GDP);

Control variables: Degree of government intervention, R&D intensity, industrialization level.

5.1.2 Model Setting

A parallel mediating effect model is adopted, and the mediating effect is tested through a three-step regression method and Bootstrap sampling (1000 times). The specific model settings are as follows:

1) Total effect model (Model 1). Testing the direct total effect of energy investment on regional growth potential: $Y = cX + \sum controls + \varepsilon_1$

where c is the total effect coefficient, and ε_1 is the random error term.

2) Mediating variable model (Model 2). Testing the impact of energy investment on industrial structure: $M = aX + \sum controls + \varepsilon_2$

where a is the effect coefficient of energy investment on the mediating variable, and ε_2 is the random error term.

3) Direct effect model (Model 3). Testing the direct effect of energy investment on regional growth potential and the role of the mediating variable after introducing the mediating variable: $Y = c'X + bM + \sum controls + \varepsilon_3$

where c' is the direct effect coefficient, b is the effect coefficient of the mediating variable on regional growth potential, and ε_3 is the random error term.

5.1.3 Analysis of Empirical Results

Table 8. Summary Results of Mediation Effect Test

Item	c Total Effect	a	b	a*b Mediatin g Effect Value	c' Direct Effect	c' (p-value)	Test Conclusion
State-owned energy industry fixed-asset investment => industrial structure => regional growth potential	0.002	0	3.53 7	-0.001	0.003	0.107	Complete mediation
State-owned petroleum processing and coking fixed-asset investment => industrial structure => regional growth potential	0.001	-0.00 2	3.53 7	-0.006	0.008	0.274	Complete mediation
State-owned gas production and supply fixed-asset investment => industrial structure => regional growth potential	-0.017	0	3.53 7	-0.001	-0.016	0.069*	Insignifica nt mediating effect
State-owned electricity, steam, and hot water production and supply fixed-asset investment => industrial structure => regional growth potential	-0.004	0	3.53 7	0	-0.003	0.141	Insignifica nt mediating effect
State-owned coal mining and washing fixed-asset investment => industrial structure => regional growth potential	-0.001	0.001	3.53 7	0.003	-0.004	0.240	Complete mediation
State-owned oil and gas extraction fixed-asset investment => industrial structure => regional growth potential	0.029	-0.00 3	3.53 7	-0.011	0.04	0.000* * *	Masking effect

Complete mediating effect (Please refer to Table 8) . The impact of investment in the energy industry, petroleum processing and coking, and coal mining and washing on regional growth potential is completely transmitted through industrial structure. Specifically, investment in petroleum processing and coking indirectly affects growth potential by inhibiting the proportion of the secondary industry, while investment in coal mining and washing plays a role by increasing the proportion of the secondary industry, verifying the heterogeneous impact of different energy industries on industrial structure;

Insignificant mediating effect. The impact of investment in gas production and supply, and electricity, steam, and hot water production and supply on industrial structure is insignificant, indicating that industrial structure does not become an intermediate path for their impact on growth potential;

Masking effect. The total effect and mediating effect of investment in oil and gas extraction have opposite signs, and the direct effect is significant, indicating that industrial structure masks part of the direct effect—investment in this industry may directly improve growth potential through other unobserved paths such as technological innovation, while the inhibitory effect of the industrial structure channel is offset by the direct effect.

5.2 Heterogeneity Analysis

5.2.1 Time-Region Two-Factor Variance Analysis

Table 9. Results of Two-way Analysis of Variance

Item	Sum of Squares	Degrees of Freedom	Mean Square	F	P	R ²	Adjusted R ²
Intercept	10.043	1	10.043	29.538	0.000* * *	0.963	0.948
Time	125.858	11	11.442	33.654	0.000* * *		
Region	319.995	24	13.333	39.217	0.000* * *		
State-owned fixed-asset investment in the energy industry (100 million yuan)	3.856	1	3.856	11.341	0.001* * *		
State-owned fixed-asset investment in petroleum processing and coking (100 million yuan)	2.738	1	2.738	8.053	0.006* * *		
State-owned fixed-asset investment in electricity, steam, and hot water production and supply (100 million yuan)	2.153	1	2.153	6.333	0.013* *		
State-owned fixed-asset investment in oil and gas extraction (100 million yuan)	0.234	1	0.234	0.687	0.409		
State-owned fixed-asset investment in coal mining and washing (100 million yuan)	20.141	1	20.141	59.242	0.000* * *		
State-owned fixed-asset investment in gas production and supply (100 million yuan)	1.136	1	1.136	3.343	0.070*		

1) Significance Test of Main Effects and Covariates

Significant main effect of time factor (Please refer to Table 9) . It indicates that between 2011 and 2022, there are significant time differences in the impact of state-owned economic energy investment on regional growth potential, which may be related to energy policy adjustments and economic cycle fluctuations in different periods—such as the effect differentiation between the period of strengthened energy transformation policies and the period of traditional energy dependence.

Significant main effect of regional factor. It indicates that there is significant heterogeneity in energy investment effects in different regions, which is closely related to differences in regional energy endowments and industrial foundations. For example, the marginal benefits of investment in resource-based regions and non-resource-based regions are different.

2) Differences in Covariate Effects

Investment in coal mining and washing, total energy industry investment, and petroleum processing and coking still have significant impacts on regional growth potential amid time and regional differences, being core energy investment variables driving the spatio-temporal differentiation of growth potential;

The impact of investment in electricity, steam, and hot water production and supply is significant, indicating that regional differences in basic energy supply have a stable impact on growth potential;

The impact of investment in gas production and supply is marginally significant, while the impact of investment in oil and gas extraction is insignificant, which may be related to its high investment scale stability and concentrated regional distribution, weakening the statistical significance of spatio-temporal differences.

6. Conclusions and Recommendations

6.1 Research Conclusions

6.1.1 Significant Heterogeneity in the Impact of Investment in Energy Sub-Sectors on Regional Growth Potential

Feature importance analysis shows that there are significant differences in the contribution of investment in different energy fields to regional growth potential. Among them, state-owned economic investment in oil and gas extraction has the highest importance and maintains a core dominant position in robustness tests, confirming the basic supporting role of upstream resource extraction links in energy security and economic growth; followed by investment in electricity, steam, and hot water production and supply, reflecting the key guarantee role of downstream energy supply in the continuity of industrial production and regional economic stability; the importance of investment in gas production and supply, petroleum processing and coking, and coal mining and washing decreases in turn, while the importance of total energy industry investment is the lowest, indicating that optimizing investment structure can better promote the improvement of regional growth potential than simply expanding scale.

6.1.2 Robustness and Endogeneity Characteristics of Core Conclusions are Verified

After replacing the explained variable and changing the econometric model, the ranking of feature importance of investment in various energy fields is highly consistent with the core conclusion, especially the dominant position of oil and gas extraction is stable, confirming the reliability of the research conclusions. Endogeneity treatment further shows that investment in electricity, steam, and hot water production and supply, and coal mining and washing have significant positive impacts on regional growth potential, while total energy industry investment shows a negative effect, indicating that over-concentrated homogeneous investment may lead to resource misallocation and weaken growth momentum.

6.1.3 Industrial Structure Plays a Heterogeneous Mediating Role in the Impact Mechanism

Mediating effect analysis shows that industrial structure is an important transmission path for energy investment to affect regional growth potential, but the direction of action varies by industry. Investment in coal mining and washing, and petroleum processing and coking produces a complete mediating effect through industrial structure optimization, while investment in oil and gas extraction has a masking effect—its direct driving role is stronger than the inhibitory effect of the industrial structure channel, and attention should be paid to other transmission mechanisms beyond structural transformation.

6.1.4 The Model Has Overfitting but Still Has Explanatory Power

The CatBoost model has an excellent fitting effect in the training set, but the explanatory power of the test set decreases. The overfitting phenomenon is closely related to the regional heterogeneity of energy investment and industry cyclical fluctuations, and also reflects the complexity of the relationship between energy investment and growth potential. A multi-dimensional analysis is needed to balance fitting accuracy and generalization ability.

6.2 Policy Recommendations

6.2.1 Optimize Energy Investment Structure and Focus on Core Fields for Targeted Efforts

On the one hand, strengthen upstream strategic energy investment. Increase technical research and development and capital input in oil and gas extraction, focus on supporting the development of unconventional oil and gas resources such as deep-sea and shale gas, and give full play to its core driving role in regional growth potential; on the other hand, ensure downstream basic energy supply. Continuously optimize the investment layout of electricity, steam, and hot water production and supply, focus on tilting toward new power systems, and reduce energy costs and supply risks in industrial production; in addition, control the scale of traditional energy investment. For investment in coal mining and washing, and petroleum processing and coking, improve resource utilization efficiency through technical transformation, and avoid the "resource curse" and structural lock-in caused by over-reliance.

6.2.2 Smooth the Industrial Structure Transmission Channel and Promote Coordination between Investment and Transformation

First, guide traditional energy investment to tilt toward structural optimization. For industries such as coal and petroleum processing, guide their integration with high-end manufacturing and green chemical industries through investment subsidies, tax incentives, and other policies to improve the quality and added value of the secondary industry; second, break the masking effect of oil and gas extraction. While increasing investment in oil and gas extraction, support supporting technological innovation incentive policies to promote the transformation of extraction technology to low-carbon and intelligent development.

6.2.3 Consider Regional Heterogeneity and Implement Differentiated Investment Strategies

For resource-endowed regions. Focus on the efficient development of advantageous resources such as coal and oil and gas, and extend the industry chain to deep processing links; for industrially intensive regions. Give priority to ensuring investment in basic energy supply such as electricity and gas, and strengthen energy support for industrial agglomeration; for transformation-lagging regions. Make up for insufficient energy investment through transfer

payments and cross-regional cooperation, focus on improving clean energy supply capacity, and cultivate new green growth drivers.

6.2.4 Improve Supporting Systems to Enhance Investment Efficiency and Sustainability

First, strengthen technical innovation support. Establish a special fund for energy technology innovation to support research and development of key technologies such as extraction efficiency improvement and low-carbon transformation, and enhance the technology spillover effect of investment; second, establish a dynamic monitoring and adjustment mechanism. Based on the cyclical characteristics of energy investment, build a "investment-growth" dynamic monitoring platform, regularly evaluate the marginal effects of investment in different fields, and timely adjust investment directions to avoid overfitting and resource misallocation;

Finally, optimize the supervision model of state-owned capital. On the premise of ensuring energy security, introduce market-oriented evaluation mechanisms, implement multi-dimensional assessment of "efficiency-security-green" for energy investment projects, and balance strategic goals and market efficiency.

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