# Trade Liberalization, Technological Progress and Energy Efficiency Improvement in China

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**Abstract** Under the background of globalization and trade liberalization of China, the energy efficiency and technological progress have improved sharply. Therefore, it is necessary to study the impact of trade liberalization on energy efficiency through technological progress. Firstly, this paper analyzes the current situation, mechanism, concept definition and theoretical analysis of trade liberalization and technological progress on energy efficiency by using the existing relevant literature and relevant official data. Secondly, according to the actual situation of China's energy efficiency, trade liberalization and technological progress and the mechanism analyzed above, the energy efficiency values of 30 provinces in this paper from 1995 to 2019 are calculated based on the Global Malmquist Luenberger (GML) index, so as to provide factual basis for the following empirical research and policy recommendations. Thirdly, the mediation effect model is constructed, and the mediation effect is tested the relationship among trade liberalization, technological progress, and energy efficiency. Then, regional heterogeneity research and robustness test are carried out. This paper discusses the impact of the differences between the east, west, north and south parts of China on the empirical results and tests the robustness of the influence path of technological progress on energy efficiency and the reliability of the regression results. Finally, according to the empirical results, this paper summarizes and puts forward some policy suggestions for promoting the coordinated development between China's energy efficiency and comprehensive opening up.

**Keywords: Trade Liberalization; Energy Efficiency; Technological Progress**

## 1 Introduction

Since the reform and opening up, China's national economy and trade liberalization have developed steadily, and then China joined the WTO, which led to unprecedented development of trade liberalization, and China's foreign trade and FDI increased rapidly. Nowadays, in the field of trade, China ranks top in the world. More noteworthy is that in the field of investment, China also attracts many foreign capital inflows. China pays equal attention to both IFDI and OFDI. The degree of trade liberalization is deepening with the implementation of a series of opening policies such as the construction of coastal special economic zones, bonded areas and tariff concessions. While steadily improving people's quality

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of life, China is also integrating into the world economy and promoting the process of economic globalization.

Under the background of seeking sustainable development, it is the common goal of the whole world to achieve efficient use of energy and save energy consumption. Although China's opening to the outside world has made the economy and foreign trade industry flourish and people's material living conditions have been qualitatively improved, the extensive development of China over the past decades has caused huge energy consumption and brought serious environmental pollution to itself. Today, there are still some areas with low industrial output and high energy consumption. Therefore, it is an important task for China to achieve the balanced development of China's high-quality economic development, high-efficiency energy utilization and comprehensive opening up.

The research on the relationship between trade liberalization and energy efficiency can be traced back to the end of last century, Grossman and Krueger(1991). This paper puts forward the mechanism of how trade liberalization affects energy consumption: the analytical paradigm of "scale, technology and structure". Scale effect refers that trade liberalization can reduce the cost of trade, promote the improvement of production capacity and the growth of trade liberalization, lead to the surge of energy consumption and the deterioration of environment and ecological system, and reduce energy efficiency. Structural effect refers to the improvement of energy consumption structure by changing industrial structure through trade liberalization. Technical effect refers to the promotion of technological progress through trade liberalization, which makes technology-intensive elements replace energy-intensive elements in the production process, thus improving energy efficiency. Technological progress is the fundamental reason for the change of energy efficiency. According to the theory of economic growth, technological progress promotes the improvement of technical complexity, updates machinery and equipment, improves production organization and promotes the development and utilization of new energy. Technological progress is not only determined by its own R&D ability, but also by trade liberalization. First, through the technology spillover effect of trade liberalization, we can absorb and transform the technology of foreign high-tech products or imitate and innovate them, so as to realize technological change. Secondly, through trade liberalization, fierce competition in the domestic market is intensified, and domestic enterprises are encouraged to update machinery and equipment and improve production technology. Therefore, the existence of technological progress brought about by trade liberalization and its degree of progress are crucial to explain the changes in energy efficiency.

It is worth noting that, firstly, in the related research fields of effective utilization of energy, most scholars study the relationship between trade liberalization and energy intensity, while few mathematicians explore the relationship between trade liberalization and energy efficiency. In fact, compared with energy intensity, energy efficiency can better reflect the economic benefits brought by unit energy, and the factors of technological progress can be separated through efficiency calculation, so it can fully reflect

the technological effect. Second, the imbalance of industrialization in China makes the regional differentiation in China obvious, with high heterogeneity in natural space and economic resources, and little overlap between energy consumption areas and energy output areas, with obvious regional differences. China's energy efficiency varies in different geographical regions. Therefore, it is realistic and necessary to study the regional energy efficiency in China.

Theoretically, according to the actual situation of China's energy efficiency and trade liberalization, this paper deeply explores the influence of trade liberalization on China's energy efficiency through technological progress by using literature research, current situation analysis and influence mechanism analysis, and then establishes an mediation effect model for in-depth empirical analysis, exploring the influence mechanism of trade liberalization on China's energy efficiency through technological progress, which can be a useful supplement to the research field of China's trade liberalization motivation to a certain extent, enriching the views and contents of China theoretical schools in the field of trade liberalization.

From the practical level, first, at the enterprise level, the research results of this paper have certain reference value for enterprises to formulate foreign investment strategies, pay attention to domestic and foreign energy efficiency policies and accurately evaluate the quality of their products and the investment risks of host countries. It is of great practical significance to pay attention to and explore the energy efficiency of a country for its sustainable development. Secondly, in terms of China's development, the research in this paper can help the coordinated development among China's high-quality economic development, high-efficiency energy utilization and comprehensive opening up, also provide some reference for the government to formulate relevant industrial energy policies and enterprises to make overseas business decisions. To sum up, this research has certain practical value and policy significance.

## 2 Literature review

At present, energy efficiency is divided into single factor energy efficiency and total factor energy efficiency by domestic and foreign scholars. Related research includes Boyd (2000) and Hu (2006). Specifically, the input factor of single factor energy efficiency only contains energy consumption, and its economic meaning can be understood as a simple ratio of input to output. In contrast, the input factors of total factor energy efficiency are not only energy consumption, but also contain labor and capital stock. It is more in line with the actual energy utilization efficiency to discuss the energy efficiency reflected by the joint action of various input factors.

Total factor energy efficiency is more practical than single factor, so this paper also adopts total factor energy efficiency as the research object. Fare et al. (1994) concluded that the analysis method of total factor energy efficiency is nonparametric analysis, which uses the input and output data to measure and calculate, and then obtains a linear convex envelope curve, and any point on the curve represents the

optimal production. Data Envelopment Analysis (DEA) and Exponential Method are representative analysis methods in nonparametric analysis, and DEA is more widely used in empirical analysis. Therefore, this paper uses the Data Envelopment Analysis (DEA) to measure the energy efficiency index, which lays the foundation for literature research.

Many scholars have studied the main factors affecting energy efficiency to a certain extent, and the main viewpoints are as follows. Li Shixiang et al. (2008) used DEA method, the energy efficiency of 13 industrial provinces in China is calculated. The results show that industrial internal structure and technological progress are important factors. Yang Xiang et al. (2019) concluded that China's energy efficiency is reflected by biased technological progress. Based on the industry data of 31 major strong industries in China, it is concluded that the opening of trade, the increase of R&D intensity and the optimization of energy consumption structure significantly promote the promotion of biased technological progress. Lin Shuwei and Guan Songli (2021) used DEA method to measure energy efficiency and analyze the influencing factors, the research shows that industrial structure, technical effect and the policy of expanding opening up have significant correlation with energy efficiency.

In today's era of seeking sustainable development, many scholars pay attention to the impact of trade liberalization on energy efficiency. A series of papers have explored the influence of trade liberalization on energy consumption and thus concluded three inconsistent conclusions. The first conclusion is that trade liberalization promotes energy consumption, that is, reduces energy efficiency. Scholars who hold this view are: Cole (2006)、Gumilang et al. (2011)、Alessandrini et al. (2011)、Nasreenand Anwar (2014)、Koengkan (2018)[9]. They used data from different regions, such as Indonesia, India, Middle East sample countries and 15 Asian countries for empirical analysis, and reached the above conclusion. The second conclusion is that trade liberalization reduces energy consumption, that is, improves energy efficiency. Scholars who hold this view are: Sbia, Shahbaz and Hamdi (2014). Shahbaz, Tiwari and Nasir (2013). They use the data of the United Arab Emirates and South Africa respectively, and use Granger causality method and ARDL boundary test method for empirical analysis to reach the above conclusions. The third conclusion is that the impact of trade liberalization on energy efficiency is uncertain and varies according to different regions. Scholars who hold this view, such as Ghani (2012), considering the differences in development levels among countries, the regression research results show that the influence of trade liberalization on national energy consumption at different development stages is inconsistent to some extent. Specifically, trade liberalization has a positive effect on the energy consumption of developing countries, but it will reduce the energy consumption of developed countries by improving the economic structure.

Grossman and Krueger innovatively put forward the mechanism of how trade liberalization affects energy consumption in 1995: the analytical paradigm of "scale, technology and structure". This analytical framework provides a theoretical basis for future generations to study how trade liberalization affects

energy consumption and its direction and extent. Many domestic and foreign scholars use the data of various countries or regions to conduct empirical tests under the framework of three influencing mechanisms. Take the following literature as an example: Cole and Elliott (2003) used this model for the first time to study the relationship between trade openness and energy consumption. Domestic scholar Zhang Youguo (2009) used the analytical paradigm, it is concluded that the growth of China's export trade will bring scale effect, which will increase energy consumption, but technological change has a significant retroaction to energy consumption and will significantly offset the promotion brought by scale effect. Xu Xiumei and Yin Xianping (2016) found that when the sum of technical effect and structural effect brought by trade liberalization is greater than the scale effect brought by trade liberalization, the greater the trade openness, the higher the energy efficiency.

Many scholars began to pay attention to technological progress in the process of studying how trade liberalization affects energy efficiency. Many literatures discuss the influence of technological progress on energy efficiency, and the following two different conclusions can be drawn by summarizing the results of literature research. The first conclusion is that technological progress will reduce energy efficiency, and scholars who hold this view are Weigend and Andreass (1996), Qin Xudong (2006)[21]. Another conclusion is that technological progress will improve energy efficiency. For example, Rui Zhou (2013). study the emerging countries after the economic system transformation, the results show that both trade liberalization and technological progress can promote energy efficiency positively. Wang et al (2020) through the mediation model, this paper discusses the transmission mechanism and effect of trade liberalization on energy intensity through energy-saving technological progress, Wang Jun et al (2021) used the data of China city, this paper study through the mediation model. Both research results show that trade liberalization significantly reduces energy intensity through energy-saving technological progress. From the above literature, we can see that among many factors affecting energy efficiency, technological progress is an important one.

To sum up, many scholars have studied the relationship between trade liberalization and energy efficiency from different angles, and the research results in the existing literature are not the same, but many important contributions have been made. There is little research on the impact of trade liberalization on energy efficiency in the existing literature, and most of them study energy consumption and energy intensity. In addition, the existing literature seldom considers the impact of regional trade openness on energy efficiency. Wang Jun et al. (2021) consider the development differences between the eastern and western regions of China, and the research results show that the impact of trade liberalization on energy intensity is the most significant in the eastern region, which obviously promotes the decline of energy intensity, followed by the central and western regions.

Based on the above discussion, this paper discusses the influence of trade liberalization on energy efficiency through the intermediary effect of technological progress, and takes into account the influence of

regional development differences between the north and the south of China on energy efficiency, which is innovative to some extent. First, this paper takes energy efficiency as the research object, which is innovative. There is little research on the impact of trade liberalization on energy efficiency in the existing literature, and most of them study energy consumption and energy intensity, so this paper has a certain degree of supplementary significance to the existing literature. Secondly, it is innovative to consider the influence of the development difference between the north and the south of China on energy efficiency in the empirical analysis. The existing literatures seldom consider the influence of regional trade openness on energy efficiency, and most of the remaining literatures that analyze the regional differences in China also analyze the development differences between the eastern and western regions of China, such as Wang Jun (2021). In this paper, the economic development differences between the north and the south are brought into the analytical framework, which enriches the viewpoints and contents of the existing research in China. Thirdly, this paper deeply analyzes the influence mechanism of trade liberalization on energy efficiency improvement through technological progress. Scholars' analysis on the influence mechanism of this research direction is more general, and there are few detailed explanations and analysis on the specific mechanism path. This paper innovatively analyzes the mechanism path of trade liberalization's influence on energy efficiency improvement through technological progress.

## 3 Mechanism analysis of the impact of trade liberalization and technological progress on China's energy efficiency

### 3.1 Influence of trade liberalization

Trade liberalization has greatly promoted a country's technological progress. According to relevant literature, its influence mechanism can be divided into the following aspects. (Chen Xiaohua et al., 2021; Sheng Bin et al., 2017)。

First, the higher the degree of trade liberalization, the more types and quantities of imported goods. By importing foreign high-tech products, domestic enterprises can study them and imitate innovation. By imitating and absorbing foreign technology for their own use, they can save a lot of capital investment needed for completely independent research and development, thus effectively improving the technical content of their own products, which is actually the embodiment of technology spillover effect. With the technological progress of a few enterprises, according to the knowledge spillover effect and the scale effect of industrial cluster, technological progress will be promoted in most enterprises, and finally the industrial structure will be upgraded, thus the technological level of the country will be improved through trade liberalization. This is the way of technology spillover effect.

Second, trade liberalization introduces a large amount of capital and attracts foreign direct investment, that is, foreign businessmen set up factories in China. The most direct change is to change the labor-cap-

ital ratio of the country, which is the proportion of capital and labor. Innovation is inseparable from the support of capital. The increase of capital proportion means the increase of capital investment in production. The increase of foreign investment brings advanced production methods to domestic enterprises, which helps to improve the technical level of local enterprises, promote social technological innovation and improve the technical content of products. This is the way of capital export effect.

Third, trade liberalization is manifested in trade tariff reduction and exemption, which will increase the import volume of foreign goods and make domestic enterprises face the crisis of market share being divided up and profits falling. In order to keep their own market share or improve their living conditions, domestic enterprises will be encouraged to update their production equipment and production methods, and actively increase capital investment in research and development, thus enhancing technological complexity and achieving the result of technological progress. This is the way of competitive effect.

Fourth, trade liberalization includes final products and intermediate products, and tariff concessions on intermediate products will enable domestic enterprises to import more kinds of intermediate products from abroad, which will further affect the technical complexity of domestic enterprises. On this basis, firstly, according to the theory of heterogeneous enterprise trade, trade liberalization promotes the export demand of domestic enterprises with high productivity; secondly, foreign enterprises will provide certain technical training to their domestic export enterprises in order to ensure the quality of imported products, and export enterprises will be more likely to have access to the advanced and strict production technology standards and production concepts of the international community; moreover, domestic enterprises will consciously improve their technical level in order to expand their foreign market share, which will be beneficial to the technological progress of domestic enterprises. This is the way of reverse technology spillover effect.

Fifth, trade liberalization is conducive to the expansion of domestic international trade scale. According to Keynesian foreign trade multiplier theory, the growth of national income will be several times that of trade, which will improve the living standards of domestic residents and change their demand preferences. According to Porter's diamond theory model, a country's consumers' high level of demand and advanced nature will force domestic enterprises to upgrade the technical content of their products to meet the market, that is, to increase research and development efforts to upgrade their technical level. This is the way of scale effect.

### 3.2 Three ways of technological progress

Since technological progress is divided into three ways, namely, independent research and development, technology introduction and imitation innovation, it is necessary to analyze the impact mechanism of trade liberalization on China's energy efficiency through the above three technical ways.

First, the impact mechanism of self-developed technological progress on energy efficiency due to the

competitive effect and scale effect of trade liberalization is as follows. First of all, self-developed technological progress can improve its own technology by virtue of its own core technological advantages and knowledge stock, and gradually eliminate old and inefficient machinery and equipment, thereby reducing costs and energy consumption, improving productivity and energy efficiency. Secondly, the self-developed technology will be used in the survey and development of new energy, which will adjust the supply and demand structure of energy and play a positive role in improving energy efficiency. Finally, enterprises with self-developed technological progress will promote the technical level of upstream and downstream and competitors, and the cooperation and competition between enterprises will make the technical upgrading activities in the industry have a virtuous circle, and ultimately improve the comprehensive technical level of the whole region, improve productivity and reduce energy consumption, that is, improve regional energy efficiency.

Second, the impact mechanism of imported technological progress on energy efficiency due to the reverse technology spillover effect and capital export effect of trade liberalization is as follows. First of all, the cause of imported technology progress is that foreign investors set up factories in the local area, and it is the general trend to cooperate with local scientific research institutions or enterprises, from which local enterprises have gained a lot of foreign advanced technologies. Advanced technology and foreign capital can change the structure of production factors, reduce energy consumption and improve energy efficiency. Secondly, foreign investment not only includes technology introduction, but also brings about the flow of high-quality talents. Through the exchange and study of human capital, local talents can be cultivated, and then through the flow of local talents, technological knowledge will spread throughout the region, and technological diffusion will also promote the energy efficiency of the whole region. Finally, imported technological progress can also intensify competition in the local market, prompting high-energy industries to withdraw from the market, or according to Kiyoshi Kojima's marginal product expansion theory, such marginal industries with high energy consumption and low energy efficiency will be transferred out of China and set up factories in foreign countries. In this way, the average energy efficiency of the country has been improved.

Third, the imitation of innovative technological progress brought about by the technology spillover effect of trade liberalization is to absorb foreign technology and then transform the new technological level obtained by innovation according to the development situation of the country. Its impact mechanism on energy efficiency is as follows. First of all, technological progress that imitates innovation has more domestic applicability and can better improve the energy efficiency of domestic products than imported technological progress. Secondly, imitation innovation reduces many unnecessary venture capital investment compared with self-developed technological progress, and draws lessons from foreign technical experience to avoid falling into the R&D bottleneck that is easy to occur in independent R&D, that is, it improves the speed and efficiency of energy conservation and productivity improvement. In addition,

the imitation of innovative technological progress mostly occurs in emerging industries with high-speed development stage, and the energy used by them is generally more environmentally friendly and clean, which also contributes to the improvement of energy efficiency in China. Finally, local enterprises will improve their energy efficiency and productivity most quickly by imitating innovative technological progress, and the improvement of their economic level will promote the income level and overall quality of consumers, and people will demand higher quality and more environmentally friendly goods, which will have an indirect impact on the improvement of energy efficiency. Figure 1 reflects the above influence mechanism.

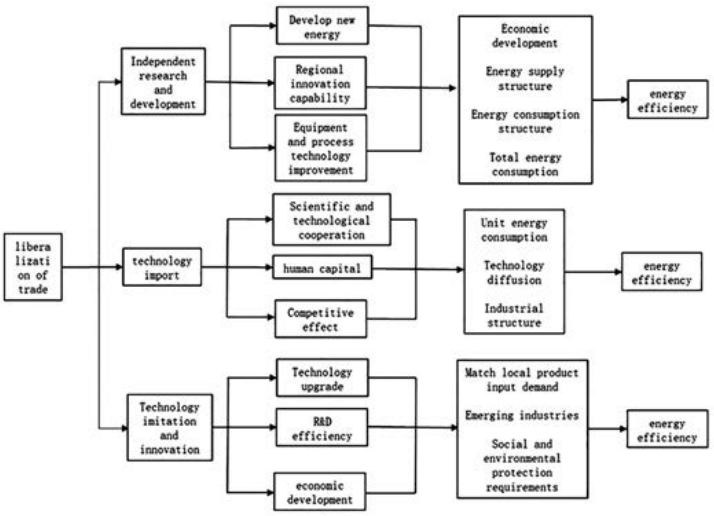


**Figure 1: Mechanism of trade liberalization affecting energy efficiency through technological progress**

To sum up, this chapter analyzes the current situation of trade liberalization, technological progress and energy efficiency and discusses the influence mechanism of trade liberalization and technological progress on energy efficiency. The analysis results show that there is a close correlation between trade liberalization and technological progress: technology spillover effect, capital output effect, scale effect, competition effect and reverse technology spillover effect of trade liberalization will all promote technological progress, and the resulting three types of technological progress: independent research and development, technology introduction and imitation innovation respectively affect the improvement of energy efficiency with their own characteristics, which constitute the influence mechanism for the improvement of energy efficiency in China.

## 4 Empirical research and analysis

The mechanism path of trade liberalization affecting energy efficiency through technological progress is analyzed. Next, based on the panel data of 30 provinces and cities in China from 1995 to 2019, we empirically test and analyze it by constructing a mediation effect model.

### 4.1 Models, indicators and data

#### 4.1.1 Model construction

Mediation effect model is an effective method to test whether mediating variables play a mediating role in the process of independent variables influencing dependent variables (Wen Zhonglin et al. (2014)). Therefore, this paper chooses the mediation effect model for empirical test. After reading a lot of literature, it is found that for the mediation effect model, this paper uses the stepwise test regression coefficient method adopted by most scholars to test whether trade liberalization will improve China's energy efficiency through the effect of technological progress. Taking technological progress as an intermediary variable, this paper examines the process of the impact of trade liberalization on energy efficiency, and the specific model is set as follows:

Firstly, whether trade liberalization can affect energy efficiency is tested, and a benchmark regression model 1 is constructed, as follows:

$$energy_{it} = \alpha_0 + \alpha_1 liberalization_{it} + \delta X_{it} + \varepsilon_{it} \quad (1)$$

Secondly, test whether trade liberalization can affect technological progress, and build model 2:

$$tech_{it} = \gamma_0 + \gamma_1 liberalization_{it} + \gamma X_{it} + \theta_{it} \quad (2)$$

Finally, whether technological progress has played an intermediary role is tested, and model 3 is constructed:

$$energy_{it} = \beta_0 + \beta_1 liberalization_{it} + \beta_2 tech_{it} + \beta X_{it} + \varphi_{it} \quad (3)$$

In all the above models, subscript i indicate provinces and subscript t indicate years, α,γ,β are coefficients of variables, and ε,θ,ϕ are random disturbance terms. *Energy* stands for energy efficiency in China, while *liberalization* stands for trade liberalization and tech stands for technological progress. X stands for the control variables, including income level, population, industrial structure and foreign direct investment level, are expressed by *income*, *population, industry* and *fdi* respectively.

#### 4.1.2 Index selection

Explained variable: According to the research purpose, this paper selects the total factor energy efficiency with unexpected output (energy) as the explained variable in this paper, which represents the energy efficiency of China. The indicators are measured by DEA model based on SBM and global Malmquist-Luenberger index. Using input and output factors, the energy efficiency index is calculated by

stata16.0 software. Among them, the input factors include energy (annual energy consumption of provinces), capital (annual fixed assets stock of provinces) and labor (annual labor force of provinces), and the output includes expected output (annual GDP of provinces) and unexpected output (carbon dioxide emissions).

Explanatory variable: This paper chooses trade liberalization as the explanatory variable of this paper. The measurement methods of this index are different in previous literature, such as the ratio of total import and export trade to a country's GDP to measure trade liberalization; The degree of deviation between the price of foreign trade goods and the actual price; A variety of indicators, such as the average tariff rate and a country's economic system, are used to measure the degree of trade liberalization in a country. On the whole, there are some defects, that is, it is difficult to accurately measure the real situation of trade liberalization, and these methods are aimed at the overall degree of trade liberalization in the country, so it is impossible to accurately measure the trade liberalization of various provinces in China. In addition, due to the search of my paper at the provincial level, the actual data of tariff rate and other related expenses still can't be got. Therefore, in order to follow the principles of data availability, operational feasibility and data continuity of variable measurement, this paper uses the following formula to express trade liberalization, which is defined as follows:

$$liberalization_{it} = \frac{trade_{it}}{gdp_{it} + import_{it} - export_{it}} \tag{4}$$

In the above formula, *i* represents the province and *t* represents the year. $Liberalizatio_{it}$ stands for trade liberalization index, $Trade_{it}$ stands for the total import and export trade of i province in t years, $GDP_{it}$ stands for the regional GDP of i province in t years, $Import_{it}$ stands for the import trade of i province in t years, and $Export_{it}$ stands for the export trade of i province in t years. The index reflects the openness of international trade in this province and city.

Intermediary variable: The former demonstrates the influence mechanism of trade liberalization on energy efficiency through technological progress, which proves the rationality of taking technological progress as the intermediary variable in this paper. Technological progress can improve energy efficiency by adjusting the ratio of capital to labor, and the output of technological progress mainly includes the increase of the number of patents. In this paper, technological progress (*tech*) is selected as an intermediate variable, and the index of technological progress is measured by logarithmic processing of the total number of patents granted each year in each province and city.

Control variables: In order to make the empirical results more convincing, other related factors should be taken into account when empirically testing the impact of trade liberalization and technological progress on energy efficiency. Based on the accuracy and availability of original data, this paper selects four indicators as control variables: income level, population, industrial structure and foreign direct investment level.

**Table 1: Specific situation of control variable index selection**

| Indicator name | Indicator description |
|---|---|
| Income level _income | Logarithmization of per capita real GDP |
| Population _population | Logarithmization of resident population at the end of year |
| Industrial structure _industry | The added value of tertiary industry/secondary industry. |
| Level of foreign direct investment _fdi | Foreign direct investment/real GDP |

Income level: The provinces and cities with higher real GDP per capita have relatively perfect environmental laws and regulations and high capital intensity in production, so the technology and equipment are more advanced and high-tech, which can further reduce energy consumption, that is, improve the energy efficiency of the provinces and cities; On the contrary, provinces and cities with low real per capita GDP have relatively low energy efficiency. In this paper, the real per capita GDP of each province and city is logarithmically processed to represent the income level.

Population: Lu Ming et al. (2018) pointed out that the innovation brought about by population agglomeration leads to the effect of technological progress, which in turn can improve energy efficiency. In this paper, the number of permanent residents in provinces and cities at the end of the year is represented by the data obtained after logarithmic processing.

Industry: There are differences in energy consumption and energy efficiency among industries. When the proportion of industries with low energy consumption in a province and city keeps rising rapidly, the proportion of industries with high energy consumption and low energy efficiency in the industrial structure decreases, and the industrial structure changes from low efficiency and high energy consumption to high efficiency and energy saving. The optimization degree of industrial structure has been continuously improved, so the overall energy efficiency of the province and city has been improved. This paper draws lessons from Xu Xuhong et al. (2018), the ratio of the added value of the tertiary industry and the secondary industry is used to represent the industrial structure of each region.

Level of foreign direct investment (fdi): FDI will promote the economic growth of this province and city, and at the same time expand production and promote the growth of energy consumption. Grossman and Krueger (1995) pointed out that international trade and FDI have both positive and negative effects on energy efficiency. In this paper, the ratio of the direct investment of foreign enterprises in each province to the actual GDP is logarithmized to show the level of foreign direct investment.

**Table 2: descriptive statistic**

| variable | (1) Sample | (2) Average | (3) Standard deviation | (4) Minimum value | (5) Maximum |
|---|---|---|---|---|---|
| Energy efficiency _energy | 750 | 1.004 | 0.0444 | 0.612 | 1.611 |
| Trade liberalization _liberalization | 750 | 0.364 | 3.250 | -71.72 | 32.55 |
| Technical progress _tech | 750 | 8.423 | 1.787 | 3.761 | 13.08 |
| Technical progress efficiency of decomposition _ teche | 750 | 0.994 | 0.0695 | 0.527 | 1.801 |
| Income level _income | 750 | 1.118 | 0.0565 | 0.978 | 1.281 |
| Population _population | 750 | 8.138 | 0.768 | 6.176 | 9.421 |
| Industrial structure _industry | 750 | 1.084 | 0.536 | 0.413 | 5.022 |
| Foreign direct investment _fdi | 750 | 804.0 | 1,462 | 4.810 | 15,179 |

#### 4.1.3 Data sources

Based on the availability of data, this paper finally selects 30 provinces in China (except Tibet Autonomous Region, because most of the data are missing) as the sample research object, and the time range is from 1995 to 2019 (because the China Energy Statistical Yearbook in 2020 has not been published, the data of energy efficiency in 2020 cannot be obtained), with a total of 750 observation values. In this paper, the index of income level may be influenced by price factors, so the actual GDP is reduced by the consumer price index (CPI) of each province over the years (based on 1995), thus eliminating the influence of price fluctuation factors on GDP. In this paper, interpolation method is used to complete the missing data. The raw data of each index selected in this paper are mainly extracted from the website of the National Bureau of Statistics, the statistical database of China Economic Net, China Energy Statistical Yearbook, China Statistical Yearbook, China Price Yearbook and statistical yearbooks of various provinces.

### 4.2 Benchmark Regression Results

The data were preliminarily tested before the empirical analysis. The results of multicollinearity test show that the variance expansion factors of explanatory variables are close to greater than 1 and less than 4, which shows that multicollinearity between variables is weak, so the model can be established. Before regression, the correlation analysis was carried out, and the results are as follows:

**Table 3: Correlation coefficient**

| | energy | liberalization | tech | income | population | industry | fdi |
|---|---|---|---|---|---|---|---|
| energy | 1 | | | | | | |
| liberalization | 0.027** | 1 | | | | | |
| tech | 0.106*** | 0.046*** | 1 | | | | |
| income | 0.076** | 0.005 | -0.173*** | 1 | | | |
| population | -0.036 | -0.037 | 0.545*** | 0.029 | 1 | | |
| industry | 0.135*** | 0.086** | 0.098*** | -0.150*** | -0.370*** | 1 | |
| fdi | 0.136*** | 0.079** | 0.447*** | -0.177*** | -0.096*** | 0.363*** | 1 |

Note: * * * indicates significant correlation at the level of 0.01 (bilateral); * * indicates a significant correlation at the level of 0.05 (bilateral); * indicates significant correlation at 0.1 level (bilateral).

According to table 4.3 the correlation coefficient matrix of each variable shows that the correlation coefficient between the explained variable energy and the controlled variable is basically significant at the level of 1%, showing a strong correlation. Rejected the original hypothesis that trade liberalization is not related to energy efficiency. The correlation between control variables is significant, but the correlation coefficient is very small, so the probability of multicollinearity in the established mediation effect model is small.

Houseman test results, p value of 0.617, the original hypothesis is accepted, and the random effect model should be chosen. Table 4.4 shows the regression results based on the mediation model (1)–(3).

**Table 4: Regression result**

| | (1)<br>energy | (2)<br>tech | (3)<br>energy |
|---|---|---|---|
| liberalization | 0.0001** | 0.0064** | 0.0001** |
| | (2.2222) | (2.0307) | (2.1236) |
| income | 0.0894*** | -2.5352*** | 0.0986*** |
| | (2.7821) | (-4.0411) | (2.9608) |
| population | 0.0008 | 1.6430*** | -0.0040** |
| | (0.5020) | (9.5279) | (-1.9899) |
| industry | 0.0095*** | 0.7065*** | 0.0077*** |
| | (6.6860) | (3.3557) | (5.1306) |
| fdi | 0.0000*** | 0.0005*** | 0.0000** |
| | (4.5799) | (2.7964) | (2.0500) |
| tech | | | 0.0032*** |
| | | | (3.2790) |
| _cons | 0.8844*** | -3.2666* | 0.8899*** |
| | (20.6924) | (-1.9102) | (21.9709) |
| N | 750 | 750 | 750 |
| R2 | 0.0396 | 0.5771 | 0.0466 |

Note: * * * indicates significant correlation at the level of 0.01 (bilateral); * * indicates a significant correlation at the level of 0.05 (bilateral); * indicates significant correlation at 0.1 level (bilateral).

According to the estimation results of model (4.1), the estimated trade liberalization parameters are positive and pass the significance test, which shows that there is a significant positive correlation between trade liberalization and energy efficiency in China. In other words, increasing the level of trade liberalization will help improve China's energy efficiency. However, model (4.1) fails to explain how trade liberalization affects energy efficiency. The control variable income level parameter value is significantly positive, indicating that the higher the income level, the higher the energy efficiency, because its environmental laws and regulations are relatively perfect, the capital intensity of production is high, and the technology and equipment are more advanced and high-tech. Population has a positive impact on energy efficiency, but it is not significant. The reason may be that it is difficult to train high-tech talents and the impact on energy efficiency is not fully manifested. There is a significant positive correlation between industrial structure and foreign direct investment level on energy efficiency.

Next, based on model (4.2), this paper examines the relationship between trade liberalization and technological progress. The results show that trade liberalization is significantly beneficial to the improvement of technological progress, and its influencing mechanism is introduced in the previous article.

Finally, based on the model (4.3), according to the judgment method of the intermediary model, it can be concluded that trade liberalization can significantly improve the energy efficiency of China through technological progress. Compared with the estimated values of parameters in model (4.1), there is basically no difference. Only the estimated value of the population index has changed in sign and significance, which may be due to the fact that the increase of population is more caused by the increase of energy consumption, and the influence of talent growth on energy efficiency is weaker than that of energy consumption, resulting in a significant negative correlation between population and energy efficiency. In a word, to some extent, the regression result of model (4.3) proves that technological progress is indeed an important intermediary channel in terms of the impact of trade liberalization on China's energy efficiency.

**4.3 Robustness test**

This paper uses the following two ways to test the regression results of the empirical analysis model to verify whether it is robust. Firstly, we regress again by replacing the technical progress indicators and observe the difference between them and the benchmark regression results. The decomposed technical progress efficiency is used to replace the original technical progress indicators, and the new technical progress indicators are represented by teche. The regression results obtained are in Table 4.5 column (1) lists that the sign and significance level of the regression results have not changed significantly, so it can be seen that the regression results have passed the robustness test, which means that changing the measurement method of technological progress indicators has not affected the influence path of technological progress on energy efficiency. This model is effective and the regression results are robust. Secondly,

the robustness of the regression results is tested by changing the measurement method to observe whether the regression results obtained by the new measurement method will change to a great extent, and whether the significance level and the positive and negative results will change. The third column of the table below is the result of robustness test, and the energy efficiency and various indicators are regressed by using the panel individual fixed model. Column (2) is the benchmark regression result of this paper, and column (3) is the regression result by using a fixed model. Comparing (2) with (3), it is found that the significance level and sign of each index coefficient have not changed significantly, only slightly fluctuating less than 0.01, indicating that the regression result has passed the robustness test.

**Table 5: Robustness test result**

| | (1) Replace the regression results of technical progress indicators. | (2) Benchmark regression results (control group) | (3) Replace with the regression result of fixed effect model. |
|---|---|---|---|
| liberalization | 0.0001* | 0.0001** | 0.0001* |
| | (1.9180) | (2.1236) | (1.1176) |
| tech | 0.1982 | | |
| | (1.4712) | | |
| income | 0.0780** | 0.0986*** | 0.1074*** |
| | (2.4522) | (2.9608) | (3.4812) |
| population | 0.0011 | -0.0040** | -0.0499* |
| | (0.7409) | (-1.9899) | (-1.7781) |
| industry | 0.0086*** | 0.0077*** | 0.0135* |
| | (5.1490) | (5.1306) | (1.8810) |
| fdi | 0.0000*** | 0.0000** | 0.0000 |
| | (5.1906) | (2.0500) | (0.8899) |
| tech | | 0.0032*** | 0.0048*** |
| | | (3.2790) | (2.8321) |
| _cons | 0.6991*** | 0.8899*** | 1.2339*** |
| | (6.5997) | (21.9709) | (5.5985) |
| N | 750 | 750 | 750 |
| r2 | 0.0396 | 0.0466 | 0.0345 |

Note: * * * indicates significant correlation at the level of 0.01 (bilateral); * * indicates a significant correlation at the level of 0.05 (bilateral); * indicates significant correlation at 0.1 level (bilateral).

### 4.4 Heterogeneity analysis

There are not only differences in the level of economic development and the degree of trade liberalization between the southern region and the northern region of China, but also great differences in the energy efficiency and the constraints of energy utilization between them. Therefore, this section divides

the regions with Qinling and Huaihe River as the boundary, with the northern region in the north and the southern region in the south for heterogeneity analysis. In addition, due to the great economic differences and uneven industrial distribution in the eastern, central and western regions of China, this paper also makes a heterogeneous analysis of the regression results in the eastern, central and western regions of China.

**Table 6: Regression results of conduction mechanism based on regional heterogeneity**

| | (1) South | (2) North | (3) East | (4) Center | (5) West |
|---|---|---|---|---|---|
| liberalization | 0.0080 | 0.0001*** | 0.0001*** | 0.1484 | 0.0369 |
| | (1.5982) | (2.7069) | (3.0801) | (1.2958) | (0.8195) |
| tech | 0.0050*** | 0.0004 | 0.0025** | 0.0136*** | 0.0037 |
| | (4.0606) | (0.3509) | (2.0162) | (3.5826) | (1.5880) |
| population | -0.0040 | 0.0001 | -0.0010 | -0.0039 | -0.0059 |
| | (-1.0781) | (0.1447) | (-0.5588) | (-0.3781) | (-1.6230) |
| industry | 0.0168*** | 0.0096*** | 0.0096*** | -0.0024 | 0.0059 |
| | (2.7321) | (10.1119) | (4.6636) | (-0.3901) | (0.8746) |
| fdi | 0.0000 | 0.0000** | 0.0000** | 0.0000*** | 0.0000 |
| | (0.4540) | (2.4484) | (2.4686) | (2.7789) | (0.1647) |
| income | 0.1235*** | 0.0789 | 0.0784** | 0.1778** | 0.0505 |
| | (3.2895) | (1.3885) | (2.0828) | (2.4414) | (0.8211) |
| _cons | 0.8349*** | 0.9011*** | 0.8917*** | 0.8622*** | 0.9540*** |
| | (13.4372) | (13.1869) | (17.6703) | (19.7630) | (12.6700) |
| r2 | 0.0657 | 0.0657 | 0.0497 | 0.1907 | 0.0228 |

Note: * * * indicates significant correlation at the level of 0.01 (bilateral); * * indicates a significant correlation at the level of 0.05 (bilateral); * indicates significant correlation at 0.1 level (bilateral).

The first column and the second column of table 4.6 are the regression results of the transmission mechanism of the impact of trade liberalization on China's energy efficiency through technological progress based on the regional heterogeneity between North and South. The parameter values of trade liberalization and technological progress in the southern region and the northern region are positive, with significant technological progress in the southern region and significant trade liberalization in the northern region, which shows that both trade liberalization and technological progress in the two regions have promoted the energy efficiency of China. The regression coefficients of trade liberalization and technological progress in the southern region are 0.0080 and 0.0050, respectively. The regression coefficients of trade liberalization and technological progress in the northern region are 0.0001 and 0.0004, respectively, which are smaller than those in the southern region, indicating that trade liberalization and technological progress have a deeper impact on energy efficiency in the southern region. There are three

reasons for this: First, for the economically developed southern region, trade liberalization is accompanied by the adjustment of industrial structure, and the southern region, which is dominated by light industry, shifts more production links to the northern region, and the industrial structure changes to the tertiary industry represented by service industry and high-tech industry, thus reducing energy consumption and improving energy efficiency. Second, the northern region is rich in coal mine energy, while the southern region belongs to the capital-intensive region. Because of the high substitution between capital and energy, with the increase of capital intensity in the southern region, energy consumption will also decrease, and energy efficiency will naturally improve. However, the northern region is underdeveloped in economy and low in technological progress, and there is no need for capital to replace energy because of its abundant energy. Third, the high level of technological foundation and technological progress in the southern region will also promote energy efficiency.

Next, China is divided into three regions: east, middle and west, and the results are shown as follows in the third to fifth columns of Table 4.6 The parameter values of trade liberalization and technological progress in the eastern, central and western regions are all positive, and they are significant in the eastern region, significant in the central region and not significant in the western region. It shows that the influence path of trade liberalization on the improvement of China's energy efficiency through technological progress has been confirmed and played a good role in the eastern region, but the influence effect is weaker from east to west. The reasons why the parameter values in the western region are not significant are as follows: With the economic development and the improvement of the level of trade liberalization, the advantages of capital-intensive, superior geographical location, talent and industrial agglomeration in the eastern region are gradually revealed, attracting more foreign investment to set up factories, and at the same time, there are more possibilities for excellent technological innovation. On the other hand, in the western region, because of the siphon effect in the eastern region, its brain drain, economic development is difficult, and the inconvenience of geographical location also makes it difficult for inland regions to develop foreign trade. The eastern part is relatively developed, the western part is relatively poor and backward, and the level of economic development in China is uneven. Based on the above situation, the role of trade liberalization in the central and western regions in improving energy efficiency through technological progress is minimal.

## 5 Conclusions

As China continues to expand its opening-up, with the promotion of trade liberalization and the emergence of green trade barriers in the world, the relationship between trade liberalization and energy efficiency has attracted more and more attention. Under this background, this paper makes a theoretical and empirical analysis of trade liberalization, technological progress and energy efficiency in China. Based

on the theoretical analysis of the literature review, concept definition, current situation analysis and action mechanism of the above three factors, this paper constructs a mediation effect model and makes an empirical analysis by using STATA software to test the relationship among trade liberalization, technological progress and energy efficiency, and draws research conclusions according to regression results, heterogeneity analysis and robustness test results.

The main conclusions of this paper are as follows: (1) After analyzing the current situation, the following conclusions can be drawn: First, the level of trade liberalization in China is constantly improving, and the tariff rate applicable to all products in China is close to the world average. With the decrease of tariff rate, the trade volume has increased on the contrary. Second, by increasing R&D investment, China's technological progress level is also steadily improving, and it is struggling to move forward on the road of becoming a powerful country in science and technology. Thirdly, the energy consumption and energy density in China are rising year by year at the same time, which shows the improvement of energy efficiency in China. (2) Through mechanism and empirical analysis, we can draw the following conclusions: trade liberalization has a significant positive effect on technological progress, which is an important intermediary channel for trade liberalization to affect energy efficiency, and trade liberalization can improve China's energy efficiency by improving the level of technological progress. (3) Through the analysis of heterogeneity, it can be seen that there are significant regional heterogeneity in the effects of trade liberalization and technological progress on the improvement of energy efficiency in China. From the east to the west of China, the farther west, the weaker the influence effect; Compared with the north of China, trade liberalization and technological progress in the south have a deeper impact on the improvement of energy efficiency in China than in the north.

According to the above research results, this paper puts forward some policy suggestions to realize the coordinated development among China's high-quality economic development, efficient energy utilization and comprehensive opening up.

First, the level of trade liberalization should be further improved. On the one hand, we can improve the level of existing free trade agreements, strengthen the reform of foreign trade system and mechanism, and integrate with international rules; Actively sign free trade agreements with other countries and build and improve China's trade network; Make good use of the Belt and Road Initiative, actively engage in trade with countries along the route on the principle of mutual benefit and win-win, relax the market access of FDI, and protect the rights and interests of foreign businessmen. On the other hand, improve the import and export structure. Actively introduce high-tech products to carry out technological imitation and innovation; Actively introduce green and low-pollution products to improve the import structure of commodities. Through brand management, export subsidies, technical capital investment and other incentive policies, we will carry out strategic trade policies to encourage enterprises to export technology-intensive products and improve the export structure. Improve the import and export structure to

reduce trade friction and promote foreign trade development.

Second, improve the level of technological progress. It is suggested that the Chinese government establish a systematic and sound science and technology policy system, provide financial support for scientific research funds and tax reduction and exemption policy support for domestic enterprises that need support and encouragement, and encourage enterprises to develop more innovative technologies to improve energy efficiency. In addition, our government can also strengthen cooperation and exchanges with other countries, vigorously introduce advanced equipment, talents and production management experience, and give full play to the technology spillover effect of FDI.

Third, improve China's energy efficiency in parallel through multiple channels. In addition to trade liberalization and technological progress, there are many factors that also play a role in promoting energy efficiency. On the one hand, adjust and optimize the energy consumption structure, reduce the use of non-renewable energy and highly polluting energy, such as fossil fuels, and increase the use of renewable clean energy, such as solar energy and wind energy. So as to reduce pollution and better meet international green standards. On the other hand, by introducing foreign capital, the government makes full use of the market competition effect to guide local enterprises to actively improve energy efficiency and eliminate industrial chains with high energy consumption and low efficiency, thus achieving the effect of promoting industrial upgrading and improving energy efficiency.

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