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The Impact of Electronic Commerce on China's Energy Consumption

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The rapid development of e-commerce in China in recent years has transformed China's economic and social production landscape as well as people's lifestyles. In addition, it has an increasing impact on China's energy consumption. Based on Melitz [Econometrica, 2003, 71 (6), 1695–1725], this paper introduces the energy efficiency parameters to propose a theoretical analysis model, and performs theoretical and empirical analysis of the impact of e-commerce on China's energy consumption using panel data at the provincial level in China. This paper suggests that the development of e-commerce can significantly enhance China's energy output efficiency, reduce energy consumption per unit of GDP, and curb the excessive growth of total energy consumption. Meanwhile, increased investment in energy conservation, technological progress, and optimized energy consumption structure can also help decrease China's energy consumption per unit of GDP, thus decreasing environmental pollution. Finally, this paper proposes policy suggestions to lower energy consumption per unit of GDP and control the excessive growth of China's total energy consumption. Compared with existing studies, the main contributions of this paper are as follows. First, because there are only a few studies on e-commerce and energy consumption, this paper further supplements and enriches relevant literature. Second, this paper proposes a theoretical model regarding the impact of e-commerce development on energy consumption, adding a new perspective to research. Third, there is a lack of adequate studies on the development of China's e-commerce landscape. While using China's e-commerce development index data at the provincial level, this paper sets up a panel data regression model and performs in-depth analysis of the impact of e-commerce development on China's energy consumption.

Keywords: e-commerce, energy consumption, energy efficiency, enterprise heterogeneity, environmental pollution, economic development

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1 INTRODUCTION

Economic reform and opening up over the past four decades has caused China's economy to boom. Given the increase in total energy consumption, China has now become the world's largest energy consumer. In 2018, China's energy consumption increased by 4.3%, contributing to 34% of the world's total energy consumption growth and retaining its first rank globally for the 18th consecutive year (BP, 2019). Against this background, the Chinese government has become aware of the problems regarding energy consumption and the resulting environmental issues. Thus, it is striving to improve energy efficiency and control the growth of total energy consumption. The industrial sector alone accounts for approximately 70% of China's total energy consumption. The growing energy consumption of industrial enterprises is the greatest contributing factor to the increase in China's total energy consumption. Therefore, improving energy efficiency and reducing energy consumption of enterprises is the top priority of the Chinese government's energy conservation efforts (Chen and Chen, 2019). For enterprises, energy efficiency and consumption levels depend on various aspects, such as production, input and sales, and is closely related to enterprise profit, production cost, and productivity. Moreover, energy efficiency and consumption are greatly affected by economic and social production as well as people's lifestyles.

The increasing popularity of the Internet and the deep integration of economic and social development with information technologies has impacted the e-commerce space. The growth in mobile networks, cloud computing, big data, artificial intelligence, Internet of Things, and block chain, have resulted in new industries, types of business, and business models. These initiatives are becoming increasingly vibrant, and the scale of e-commerce is growing and playing an increasingly important role in economic and social development. By unleashing the potential of novel technologies, e-commerce significantly slashes the costs for supplier searching and product development, transportation, and distribution and improves productivity (Goldfarb and Tucker, 2019). In contrast, owing to e-commerce platforms, many products and services can be obtained directly through phones, bridging the distance between consumers and producers, and improving consumer selection efficiency (Xu et al., 2020). Therefore, the development of e-commerce has significantly shifted economic and social production and lifestyle, and enormously reduced production costs and improved productivity, positively impacting the energy consumption of enterprises.

In addition, in terms of literature and theoretical mechanisms research, there are few studies on the impact of e-commerce on China's energy consumption. Existing research has mainly conducted analyses based on cases and statistics; thus, further theoretical research is needed. Moreover, although e-commerce has been thriving in China in recent years, there is scarce knowledge on the impact of e-commerce on China's energy consumption. Therefore, based on the model of Melitz (2003), this paper considers a monopolistic competitive market with many firms and customers, where each firm specializes in one variety of products and introduces energy efficiency parameters to propose a theoretical analysis model. This ensures theoretical and empirical analysis of the impact of e-commerce development on China's energy consumption using panel data at the provincial level in China from 2014 to 2017.

Compared with existing studies, the main contributions of this paper are as follows: First, because there are only a few studies on e-commerce and energy consumption, this paper further supplements and enriches existing literature. Second, this paper proposes a theoretical model regarding the impact of e-commerce development on energy consumption, adding a new perspective to research. Third, there are limited studies on the development of China's e-commerce landscape. While using China's e-commerce development index data at the provincial level, this paper sets up a panel data regression model and performs in-depth analysis of the impact of e-commerce development on China's energy consumption.

Section 2 of this paper introduces a literature review. **Section 3** proposes the theoretical model on the impact of E-commerce development on energy consumption. **Section 4** proposes the econometric model and processes relevant data. **Section 5** analyzes the result obtained from panel data research. The last section consists of research conclusions and suggestions.

2 LITERATURE REVIEW

2.1 E-Commerce Development

According to the research purpose of this paper, we focus on the analysis of the impact of e-commerce on economic and social production and life. To begin with, e-commerce can significantly reduce costs for information search and product prices, and better match the resources between the demand and supply side (Ellison and Ellison, 2009; Kroft and Pope, 2014). Moreover, lower information search cost will significantly change companies' production and management patterns and optimize allocation of production factors globally, thus reducing overall production costs. (Agrawal et al., 2016). Gunasekaran et al. (2002) propose that e-commerce will play an important role in the operation management of firms in the 21st century and enable firms to obtain market information and facilitate product and service transactions in a timely manner. Terzi (2011) indicates that e-commerce can also help firms learn the demand of the international market, reduce the cost of market access, shorten the business cycle, and increase trade volume in a timely manner.

E-commerce can significantly cut down transportation and distribution costs. Owing to e-commerce platforms, consumers can buy commodities online, and the purchased goods can be delivered to them *via* robust logistics networks, skipping the intermediate sellers, and saving transportation costs that would have been incurred in conventional business models (Forman et al., 2009; Pozzi, 2013). Companies may also purchase raw materials online and save transportation costs (Kotabe et al., 2008). Iyer et al. (2009) propose that the integration of the business-to-business supply chain can significantly reduce the costs of, for instance, inventory and pertinent procurement, manufacturing, warehousing, after-sales service, and order management; improve the accuracy of production and delivery time; and enhance operation management.

Thirdly, e-commerce can greatly enhance productivity (Draca et al., 2009). Research using panel data of cross-border enterprises by Bloom et al. (2012) reveals that e-commerce can significantly promote the optimization and reconstruction of the organization and management of companies, thereby improving their production efficiency. Yu et al. (2016) propose that the Internet is fundamental for improving the efficiency of logistics and supply chain management. In light of the above studies, e-commerce has significantly changed economic and social production, as well as people's lives. Moreover, it has an important impact on companies' decision-making regarding production investment.

2.2 China's Energy Consumption

Many studies on China's energy consumption have emerged in recent years. They have examined the factors affecting China's energy consumption, which provides important references for making policies regarding China's energy conservation and emission reduction. Some scholars have examined China's rapid economic development, believing that it is the key factor to energy consumption growth (Tang et al., 2018). In economic development, the rapid urbanization and industrialization in China has further increased China's demand for energy consumption, gradually turning China into the world's biggest energy consumer (Madlener and Sunak, 2011; Zhao and Zhang, 2018). For example, Zhao and Zhang (2018) explore how the process of urbanization affected energy use in China from 1980 to 2010. The results of the analyses show that for every 1% increase in the urban population relative to the total population, national energy consumption rose to 1.4%. Further, urbanization has increased energy consumption along three main pathways: urban spatial expansion, where urban sprawl has increased energy consumption in new buildings and the transport sector; urban motorization, which induces energy-intensive transportation; and the rising quality of energy intensive lifestyles.

Some scholars have also explored the impact of technological progress, postulating that technological upgrades can promote industrial upgrading and improve energy efficiency, which mitigate China's energy consumption (Zha et al., 2012; Song et al., 2017). For example, Liu et al. (2019) conduct panel analysis to evaluate the effects of a structural economic shift from the industrial to the tertiary sector in energy efficiency on energy consumption using data for 30 Chinese provinces from 1995–2015. Their findings demonstrate that at the national level, the structural shift to the tertiary sector and industrial technology upgrading can reduce China's energy consumption. In addition, some scholars argue that energy price is also an important factor affecting energy efficiency and consumption. The government's energy policies and energy investments are crucial in improving energy efficiency and reducing energy consumption (Ma et al., 2017; Deng et al., 2018; Guo et al., 2018). For example, Valizadeh et al. (2018) show that energy prices had a significant and positive effect on energy consumption efficiency. Furthermore, in their analyses of energy, urbanization, economy, and prices in 186 countries from 1980 to 2015, Wang et al. (2019) reveal that energy prices affected energy consumption efficiency positively both in high and lower-middle income countries. However, it has a negative impact on energy consumption efficiency in upper-middle income countries.

Finally, several scholars have explored the structure of energy consumption and believe that mitigating the consumption of fossil fuels such as coal and petroleum, and turning to clean energy sources such as natural gas can improve China's overall energy efficiency and reduce energy consumption. They advise the Chinese government to promptly assess and adjust energy subsidy policies and continuously improve the structure of energy consumption (Feng et al., 2009; Liu and Li, 2011; Sun et al., 2018). For example, Sun et al. (2018) show that reducing high carbon energy, implementing energy price reform, carbon tax, and clean energy subsidy can help adjust China's energy consumption structure to improve overall energy efficiency and decrease energy consumption.

2.3 E-Commerce Development and Energy Consumption

Despite the lack of research on the impact of e-commerce on China's energy consumption, several scholars have explored the impact of e-commerce on the energy consumption of other countries and of the world. **Figure 1** shows that according to existing relevant studies, the development of e-commerce may have positive and negative impacts on energy consumption. Some studies suggest that e-commerce can significantly improve productivity, reduce energy consumption during production, transportation, and sales, improve energy efficiency, promote the use of renewable energy, and improve the energy output rate, thus reducing energy consumption (Reijnders and Hoogeveen, 2001; May et al., 2017). Meanwhile, other scholars emphasize that e-commerce has profoundly influenced our lives, stimulated consumer demand for many products, and increased energy demand in many fields, such as packaging, thereby decreasing energy output rate and increasing total energy consumption (Sadorsky, 2012; Pålsson et al., 2017; Dost and Maier, 2018). Therefore, the net effect of e-commerce development on the average energy output rate and energy consumption of enterprises should be analyzed theoretically and empirically. In addition, existing research has mainly conducted analyses based on cases and statistics, and more theoretical research is needed. Although e-commerce has been thriving in China in recent years, the impact of e-commerce on China's energy consumption is yet to be clarified. Therefore, this paper conducts theoretical and empirical analysis of the impact of e-commerce on China's energy consumption.

3 THEORETICAL ANALYSIS

Melitz (2003) proposed a model with firm heterogeneity of productivity to analyze how international trade impacts intra-industry reallocations and aggregated productivity (Tang et al., 2018). Based on Melitz (2003), this paper considers a monopolistic competitive market with many firms and customers where each firm specializes in one variety of product, and introduces the energy efficiency parameters to propose a theoretical analysis model to study the impact of E-commerce development on energy consumption at the enterprise level.

3.1 Modelling

Firstly, the model of Melitz (2003) establishes the customer utility function $U = [\int_{\omega \in \Omega} q(\omega) d\omega]^{1/\rho}$ in the form of constant elasticity of substitution (CES), where $0 < \rho < 1$, product ω consumed by consumers belongs to the product cluster Ω, and we can obtain the elasticity of substitution of two products $\sigma = 1/(1-\rho) > 1$. Then, the demand quantity for product ω can be represented as $q(\omega) = Q[p(\omega)/P]^{-\sigma}$, and the total expense for product ω can be

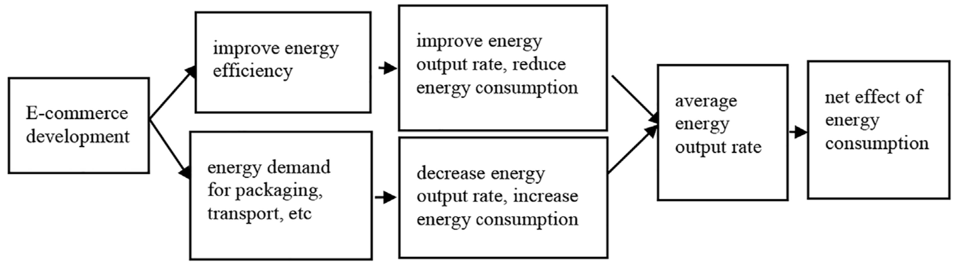

FIGURE 1 | Analysis of theoretical impact mechanism.

represented as $r(\omega) = R[p(\omega)/P]^{1-\sigma}$. Q is the total demand quantity of the product, P is the price index, and R = PQ is the total expense.

Regarding the producer, to make analysis easier, this paper endogenizes energy consumption based on the model proposed by Melitz (2003). The paper assumes that the enterprise only inputs one variable production factor, namely energy, e, and in the meantime assumes labor and capital to be fixed exogenous production factors and fixed cost to be f. In addition, we standardize the price of e as 1, enabling us to arrive at the profit function of the enterprise, as below:

$$\pi(\varphi) = r(\varphi) - l(\varphi) = \frac{r(\varphi)}{\sigma} - f \tag{1}$$

Where φ is the output rate per unit energy, which is an inverse function of enterprise energy consumption; in other words, the greater the φ, the lower the energy consumption per unit of GDP. Moreover, **Eq. 1** shows that enterprise profit is the gap between operating profit $r(\varphi)/\sigma$ and fixed costs, and the proportion of operating profit to enterprise revenue $r(\varphi)$ is $1/\sigma$. Enterprise profit, operating profit, and enterprise revenue are monotonically increasing functions of output rate φ.

Next, assuming that enterprise profit function $\pi(\varphi) = 0$, we obtain the threshold value φ^* of energy output rate, suggesting that the enterprise is operational only when the energy output rate $\varphi > \varphi^*$.

We assume that the initial distribution function of energy output rate φ is $g(\varphi)$ and there exists the continuous cumulative distribution function $G(\varphi)$. In Melitz (2003) model, we can obtain the mean energy output rate $\tilde{\varphi}$:

$$\tilde{\varphi}(\varphi^*) = \left[\frac{1}{1 - G(\varphi^*)} \int_{\varphi^*}^{\infty} \varphi^{\sigma-1} g(\varphi) d\varphi\right]^{\frac{1}{\sigma-1}} \tag{2}$$

In **Eq. 2**, $1 - G(\varphi^*)$ is the exogenous probability that the enterprise is operating, which means that the mean energy output rate $\tilde{\varphi}$ is a monotonically decreasing function for threshold value φ^*, namely, $\partial\tilde{\varphi}(\varphi^*)/\partial\varphi^* < 0$. Thus, we focus specifically on analyzing the impact of e-commerce development on the threshold value φ^* of energy output rate, thereby obtaining the change of the average energy output rate, and finally, the change of the output energy consumption.

3.2 Equilibrium Analysis of Theoretical Model

As mentioned earlier, e-commerce can reduce information asymmetry and transaction costs, which can significantly improve business efficiency. Based on Melitz (2003), we assume that e-commerce ϕ can significantly reduce exogenous fixed costs f such as labor and capital, thus improving the operating profit of enterprises; that is, $\partial f(\phi)/\partial\phi < 0$. Together with **Eq. 1**, we can further conclude that $r(\varphi^*) = \sigma f(\phi)$. As enterprise revenue $r(\varphi)$ is a monotonically increasing function of energy output rate φ, $r(\varphi^*) = \sigma f(\phi)$ is also a monotonically increasing function of threshold value φ^*. Therefore, e-commerce ϕ is monotonically decreasing for threshold value φ^*, namely, $\partial\varphi^*/\partial\phi < 0$.

Finally, based on the assumption and conclusion of **Eq. 2**, we can obtain **Eq. 3**:

$$\frac{\partial\tilde{\varphi}[\varphi^*(\phi)]}{\partial\phi} = \frac{\partial\tilde{\varphi}}{\partial\varphi^*} \bullet \frac{\partial\varphi^*}{\partial\phi} > 0 \tag{3}$$

We can conclude from **Eq. 3** that e-commerce ϕ is monotonically increasing for average energy output rate $\tilde{\varphi}$. Hence, we can verify the assumption of this paper that with the development of e-commerce, the average energy output rate of enterprises will improve significantly, and energy consumption will reduce greatly.

4 EMPIRICAL MODEL AND DATA

4.1 Empirical Model

Owing to the lack of enterprise level data, referring to the research ideas and methods of Tang (2022), this paper initiates a panel regression model at the provincial level to analyze the impact of E-commerce development on China's energy consumption:

$$\ln energy_{it} = \alpha + \beta_1 \ln ecommerce_{it} + \beta_2 * X_{it} + \varepsilon_{it} \tag{4}$$

Where i represents the province, t represents the year, and the explained variable $\ln energy_{it}$ denotes the energy consumption of province i in year t. Their logarithms are taken. The explanatory variable $\ln ecommerce_{it}$ denotes the e-commerce development index of province i in year t, and their logarithms are taken as well. The variable X_{it} is another control variable, and ε_{cijt} is a random error term.

TABLE 1 | E-commerce development index system.

Level I Index	Level II Index
Scale index	The proportion of companies with e-commerce activities out of all companies nationwide The proportion of e-commerce turnover in the total e-commerce turnover nationwide The proportion of online retail sales in the total online retail sales nationwide The proportion of online shoppers in the total number of those nationwide
Growth index	Growth rate of companies with e-commerce activities Growth rate of e-commerce turnover Growth rate of online retail sales Growth rate of online shoppers
Penetration index	The proportion of companies with e-commerce activities in the total number of companies of the province The proportion of online shoppers in the total population of the province The proportion of online retail sales in the total sales of the province
Support index	Foundation environment Logistics environment Human resources environment

As regards estimation method, this paper uses a fixed effects model (FEM) and a random effects model (REM) as benchmark models for analysis to obtain the preliminary results. Meanwhile, to further solve the endogenous problem and ensure the unbiasedness and effectiveness of the estimated results, this paper employs a panel instrumental variable (IV) regression model to conduct an empirical analysis. Moreover, we performs robustness test on the preliminary results, finally determining the impact of e-commerce development on China's energy consumption.

4.2 Data

The e-commerce development indexes at the provincial level from 2014 to 2017 are derived from the China e-commerce Development Index Reports from 2015–2018, which were released jointly by relevant government authorities, enterprises, and academic institutions, such as the National Development and Reform Commission, the Ministry of Commerce of the People's Republic of China, AliResearch, Tsinghua University, the Central University of Finance and Economics, the Chinese Academy of Social Sciences, and Ebrun Research. The report comprehensively evaluates the e-commerce development level of China's provinces. Additionally, provincial-level indicators, such as energy consumption, energy conservation expenditure, technology market turnover, government finance, and energy consumption structure, are sourced from the China Statistical Yearbook, the China Energy Statistical Yearbook, and the China Statistical Yearbook on Science and Technology.

4.2.1 Energy Consumption (lnenergy)

This paper measures the energy efficiency and output consumption of all provinces using the energy consumption per unit of GDP. The unit is the consumed standard coal (ton) per 10,000RMB worth of GDP, and analysis is performed using logarithms.

4.2.2 E-Commerce Development (lnecommerce)

As mentioned above, the evaluation of e-commerce development is quite complex and nuanced. This paper employs the e-commerce development indexes at the provincial level from the China e-commerce Development Index Report for measurement and performs an empirical analysis using logarithms. As shown in **Table 1**, e-commerce development indexes include four Level I indexes and fourteen Level II indexes, such as scale index, growth index, penetration index, and support index. The scale and growth indexes directly reflect the level of e-commerce development; moreover, it mainly indicates the status of e-commerce development, and the growth index depicts its future and expectation. The penetration index and the support index reflect the external environment of e-commerce development; the penetration index measures the impact of e-commerce on the economic environment, whereas the support index measures the environmental support for e-commerce. Therefore, e-commerce development indexes comprehensively evaluate and measure the e-commerce development of China's provinces.

The data in the report is mainly derived from the Statistical Yearbook of National Bureau of Statistics and the open data released by Department of Commerce of various provinces. In addition, the report determines the weight by combining subjective and objective methods (coefficient of variation). Specifically, we assume there are n indicators, and the coefficient of variation of these n indicators can be represented as $V(i) = s_i/\bar{x}$, where, s_i represents the standard deviation of indicator i, and $\bar{x}$ represents the mean value of the sample; thus, the weight of various indicators is $\omega_i = V(i)/\sum_{i=1}^{n} V(i)$.

4.2.3 Energy Conservation Expenditure (lnreduce_exp)

Energy conservation expenditure can significantly affect energy efficiency, and is a key factor affecting energy consumption. Therefore, this paper considers the energy conservation expenditure of the governments at provincial level (unit: 100 million RMB) as the control variable and performs analysis using logarithms.

4.2.4 Technology Market Turnover (lntech)

Research suggests that technology is a critical factor affecting energy consumption, and technological progress can improve the energy efficiency of enterprises and contribute to reducing energy consumption. Thus, this paper analyzes the technology market turnover (unit: 10,000RMB) at the provincial level as a control

TABLE 2 | Descriptive statistics.

Variable	Mean	Std.Dev	Min	Max	Pre-estimated coefficient sign
lnenergy	−0.402	0.468	−1.368	0.634	
lnecommerce	3.009	0.572	2.027	4.266	−
lnreduce_exp	4.830	0.560	3.148	6.128	−
lntech	13.83	1.739	8.783	17.62	−
lnfinance	7.654	0.809	5.474	9.334	−
lnfossil	9.493	0.828	7.270	10.80	+
lngas	3.925	0.836	1.533	5.471	−

variable. Technology market turnover can more directly reflect the level of transforming technological progress into production achievements compared with other indicators measuring technological progress. It has a more direct impact on energy consumption. Finally, this paper performs an empirical analysis using the logarithm of technology market turnover.

4.2.5 Government Finance (lnfinance)

As mentioned earlier, the economy of a region is an important factor affecting its energy consumption, and government finance is an important indicator and factor that reflects and affects the level of economic development. A more developed economy results in higher governmental revenue, which in turn, will lead to more investment in energy conservation. This reduces energy consumption to a great extent. As energy consumption (lnenergy) is obtained by deflating total energy consumption and GDP, to avoid multicollinearity, this paper takes government finance at the provincial level (unit: 100 million RMB) as the control variable and performs analysis using its logarithm.

4.2.6 Fossil Fuel Consumption (lnfossil) and Natural Gas Consumption (lngas)

Research suggests that energy consumption structure is a key factor affecting total energy consumption. If a region consumes more fossil fuels, its total energy consumption tends to be high. Otherwise, if a region consumes more clean energy, such as natural gas, its total energy consumption is relatively lower. Therefore, this paper considers both fossil fuel consumption and natural gas consumption of all provinces as control variables when performing analysis. Fossil fuel consumption is the sum of coal, coking coal, oil, and other fossil fuels consumed (unit: 10,000 ton). For clean energy, we use the consumption of natural gas (unit: 100 million m^3). Finally, we use the logarithms of the above indicators for the empirical analysis.

Finally, the descriptive statistical analysis of the entire sample is conducted to further understand the characteristics of the research data, and the results are shown in **Table 2**.

5 EMPIRICAL RESULT ANALYSIS

5.1 Analysis of the Preliminary Estimated Results

Before the estimation and analysis of panel regression model, this paper first conducts Harris Tzavalis Unit Toot Test (HT test) on

TABLE 3 | Harris-Tzavalis unit-root test.

Variable	Statistic	z	*p*-value
lnenergy	−0.9047	−5.5989	0.0000
lnecommerce	−0.8576	−5.1963	0.0000
lnreduce_exp	−0.8497	−5.1291	0.0000
lntech	−0.8185	−4.8616	0.0000
lnfinance	−0.0069	2.0794	0.9812
lnfossil	−0.9077	−5.6245	0.0000
lngas	−0.3050	−0.4706	0.3190

TABLE 4 | Kao test for cointegration.

Ho: No cointegration	Number of panels = 30	
Ha: All panels are cointegrated	Number of periods = 2	
Cointegrating vector: Same		
Panel means: Included	Kernel: Bartlett	
Time trend: Not included	Lags: 0.97 (Newey-West)	
AR parameter: Same	Augmented	lags:1
	Statistic	*p*-value
Modified Dickey-Fuller t	−6.9138	0.0000
Dickey-Fuller t	n.a.	n.a.
Augmented Dickey-Fuller t	n.a.	n.a.
Unadjusted modified Dickey-Fuller t	0.9511	0.1708
Unadjusted Dickey-Fuller t	−3.9976	0.0000

each variable. The estimation results in **Table 3** reveal that the series are non-stationary (variable lnfinance and lngas). Thus, this paper employs the Kao test for cointegration to demonstrate long-run cointegration. **Table 4** reports three different test statistics that can be calculated. Two of the corresponding *p* values are 0.0000 and the other is 0.1708. According to the majority principle, this paper can draw the following conclusion—strongly reject the original assumption of “No cointegration” at the 1% level, and confirm long-run cointegration. Therefore, the panel regression model in this paper is reasonable.

Table 5 reflects the preliminary results of the impact of e-commerce development on China’s energy consumption based on the panel model. As both the F test and the Breusch and Pagan Lagrangian multiplier test suggest that the results of Ordinary Least Square (OLS) are biased, we have not posted the results of OLS. Although the results of the Hausman test show that the FEM is more efficient than the REM, we still report the

TABLE 5 | Panel regression model analysis result.

Model	(1) Fixed effects	(3) Random effects	(2) Fixed effects	(4) Random effects
Variables	lnenergy	lnenergy	lnenergy	lnenergy
lnecommerce	−0.0761***	−0.0913***	−0.0263*	−0.0361**
	(0.0231)	(0.0241)	(0.0158)	(0.0163)
lnreduce_exp			−0.0774**	−0.0614**
			(0.0320)	(0.0300)
lntech			−0.0247*	−0.0288**
			(0.0140)	(0.0133)
lnfinance			−0.250***	−0.394***
			(0.0748)	(0.0541)
lnfossil			0.181**	0.288***
			(0.0874)	(0.0457)
lngas			−0.127***	−0.0353
			(0.0407)	(0.0345)
Constant	−0.173**	−0.127	1.085	0.819*
	(0.0698)	(0.101)	(0.920)	(0.447)
F test	106.42		69.73	
	(0.0000)		(0.0000)	
LM test		126.63		143.25
		(0.0000)		(0.0000)
Hausman test	13.72		18.15	
	(0.0011)		(0.0113)	
Observations	120	120	120	120

*Standard errors in parentheses below regression coefficients, ***p < 0.01, **p < 0.05, *p < 0.1.*

estimated results of REM to ensure the robustness of the estimated results. As shown in **Table 5**, both the results of the FEM and REM suggest that the e-commerce development index has a negative impact on energy consumption per unit of GDP, indicating that e-commerce can significantly improve energy output rate and reduce energy consumption per unit of GDP, which verifies our assumption. Specifically, the results of FEM demonstrate that if e-commerce development is increased by 1%, energy consumption per unit of GDP will be significantly reduced, by approximately 0.0263 percentage points.

The results in respect of control variables reveal that energy conservation expenditure (lnreduce_exp) has a significant negative impact on energy consumption per unit of GDP, suggesting that increased energy conservation expenditure by the government can significantly reduce output energy consumption. Moreover, technology market turnover (lntech) has a significant negative impact on energy consumption per unit of GDP, suggesting that the introduction and application of technology can significantly improve energy efficiency and reduce energy consumption. Government finance (lnfinance) also has a significant negative impact on energy consumption, indicating that in regions with higher levels of economic development, government revenue is higher and government has a stronger ability to reduce energy consumption. Finally, with respect to energy consumption structure, the findings suggests that fossil fuel consumption (lnfossil) has a significant positive impact, whereas natural gas consumption (lngas) has a significant negative impact on energy consumption. This suggests that increased consumption of fossil fuels such as coal, coking coal, and oil does not help reduce energy consumption, whereas increased consumption of clean energy such as natural gas can help reduce energy consumption.

5.2 Robustness Test

To avoid the interference of endogenous factors and ensure the unbiasedness and effectiveness of the estimated results, based on the results of the Hausman test, this paper conducts deviation based on the fixed effects model, and performs empirical analysis using IV estimation and generalized method of moments. For IV, we use four lags each of the Internet (%) and the mobile phone penetration (phone/100 persons) for analysis. The reasons for this approach are: first, Internet penetration and mobile phone penetration are important foundations for e-commerce development and are closely related to the endogenous variable, thus avoiding the issue of a weak IV. Second, Internet and mobile phone penetration of the lagged stage have a weaker correlation with energy consumption of the current stage, thus ensuring the sound exogeneity of the IV. As shown in **Table 6**, both the F test and the Anderson–Rubin Wald test conducted in Stage 1 suggest no issue regarding a weak IV, while the under-identification test suggests that the IV can be estimated and identified; in contrast, overidentification test shows that the IV has sound exogeneity. Therefore, the estimated results of the IV are unbiased and effective.

Specifically, as shown in Columns (1)–(7) in **Table 6**, the IV estimation results show that whether other variables are controlled or not, the e-commerce development index (lnecommerce) shall always have a significant negative impact

TABLE 6 | Instrumental variables' estimation results with panel data (GMM).

Variables	(1) Lnenergy	(2) Lnenergy	(3) Lnenergy	(4) Lnenergy	(5) Lnenergy	(6) Lnenergy	(7) Lnenergy
lnecommerce	−0.247***	−0.119***	−0.183***	−0.127***	−0.251***	−0.168***	−0.0502*
	(0.0418)	(0.0358)	(0.0421)	(0.0325)	(0.0407)	(0.0461)	(0.0270)
lnreduce_exp		−0.204***					−0.0827**
		(0.0271)					(0.0371)
lntech			−0.0456**				−0.0239*
			(0.0192)				(0.0142)
lnfinance				−0.488***			−0.250***
				(0.0758)			(0.0961)
lnfossil					0.460***		0.173*
					(0.136)		(0.0911)
lngas						−0.213***	−0.114***
						(0.0560)	(0.0421)
First-stage F test	35.65	26.52	28.37	27.76	34.64	18.65	25.94
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Anderson–Rubin	69.54	15.10	35.98	18.12	78.26	21.71	5.89
Wald test	(0.0000)	(0.0005)	(0.0000)	(0.0001)	(0.0000)	(0.0000)	(0.0527)
Underidentification	29.536	27.503	21.570	27.476	29.316	22.091	24.916
test	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Overidentification	1.753	1.262	2.004	0.672	1.127	0.384	2.266
test	(0.1855)	(0.2612)	(0.1569)	(0.4125)	(0.2884)	(0.5355)	(0.1322)
Observations	120	120	120	120	120	120	120

*(1) Standard errors in parentheses below regression coefficients, ***p < 0.01, **p < 0.05, *p < 0.1. (2) The numbers in parentheses under the tests are p values. (3) The under-identification test is the Kleibergen–Paap rk LM, statistic test. (4) The overidentification test is the Hansen J statistic, which accepts the original assumption at the level of 10%, suggesting that the assumption is rational. (5) The IV, in Column 6 is four lags of Internet penetration and four lags of the logarithm of mobile phone penetration. In other columns, it is four lags each of the logarithm of Internet and mobile phone penetration.*

on energy consumption per unit of GDP (lnenergy), which further verifies the assumption proposed in this paper. In other words, with the development of e-commerce, the average energy output rate of enterprises will improve and energy consumption will reduce significantly. Simultaneously, the panel instrumental variable regression results also show that if the development level of e-commerce increases by 1%, the energy consumption per unit of GDP will significantly reduce by about 0.0502 percentage points, slightly higher than the preliminary regression results of 0.0263 percentage points. Despite this, the overall impact is still less than 0.1 percentage points, and the impact range needs to be further improved, which also confirms the relevant conclusions of previous literature research to a certain extent. According to global comparisons with other studies, the development of e-commerce has positive and negative effects on energy consumption (Dost and Maier, 2018), which indicates that China needs to further promote the proportion of e-commerce in economic and social development, continuously endorse the substantial increase of enterprise productivity, and bolster the positive role of e-commerce development in reducing energy consumption.

Regarding other control variables, whether control variables are added separately or together, the results of control variables will remain consistent with those in **Table 5**. Our findings shows that on the one hand, increasing energy conservation expenditure, introducing new technologies, and increasing government finance can significantly reduce China's energy consumption. On the other hand, optimizing energy consumption structure, reducing the consumption of fossil fuels such as coal, coking coal, and oil, and promoting the consumption of clean energies such as natural gas will also decrease China's energy consumption.

6 CONCLUSION, POLICY IMPLICATIONS, AND FUTURE IMPROVEMENT

With the rapid development of the economy, China's energy consumption ranks the highest in the world. Improving energy efficiency and controlling energy consumption have become important factors of the sustainable and stable development of China's economy. Meanwhile, with the wide spread of the Internet, China's e-commerce is also flourishing, and its impact on economic and social production and people's lives is also increasing, which has a major impact on China's energy consumption. Against this background, based on the model by Melitz (2003), this paper has performed theoretical and empirical analysis of the impact of e-commerce development on China's energy consumption using the panel data at provincial level from 2014 to 2017. Our findings suggests that e-commerce development can significantly improve China's energy output rate and reduce energy consumption per unit of GDP, which helps curb the excessive growth of total energy consumption and reduce environmental pollution. Moreover, the research also suggests that increased energy conservation expenditure and government finance and technological progress can significantly lower China's energy consumption. Besides, reducing the consumption of fossil fuels such as coal, coking coal, and oil, while promoting the harnessing of clean energies such as natural gas, can reduce China's energy consumption per unit of GDP.

The suggestions of this paper are as follows. The Chinese government should expand investment in the Internet sector, develop the digital economy, promote deep integration of e-commerce and production, continuously reduce costs for production, transportation, and sales, and improve the energy efficiency of enterprises, thereby creating favorable conditions for controlling excessive energy consumption. Specific recommendations are as follows: first, according to the relevant research on carbon energy consumption of e-commerce enterprises, from the current greenhouse gas emission information disclosed by global e-commerce enterprises, the indirect carbon emissions generated by suppliers account for a large proportion of the total carbon emissions of enterprises. Moreover, global e-commerce platforms, including China, generally have room for improvement at the supplier management level. Therefore, e-commerce enterprises should establish complete supplier environmental management principles and access principles, and prioritize to suppliers with low carbon and low energy consumption. Second, according to relevant research, for e-commerce enterprises, logistics is the largest carbon emission and energy consumption. To this end, the Chinese government can significantly reduce energy emissions by promoting the use of new energy electric vehicles to replace fuel vehicles. Third, according to relevant research, the storage of traditional energy consumption of e-commerce enterprises is also large. To this end, the Chinese government should urge e-commerce enterprises to form large-scale renewable energy applications in office, storage, data centers, and other links.

Additionally, the Chinese government should adjust and optimize the energy fiscal policy, and continue to increase the expenditure on energy conservation and protection to continuously reduce the level of energy consumption per unit of GDP. Efforts should be made to control the excessive growth of total energy consumption through the following possible methods. First, the Chinese government should constantly improve the upgrading of industrial technology, increase investment in new technologies, especially energy technology research and development, and introduce new energy saving technologies, processes, products, and standards, which are widely used in the production processes of enterprises. This will facilitate improved energy utilization efficiency of enterprises and reduce the energy consumption level of enterprises. Second, the Chinese government should continue to optimize the energy consumption structure, increase subsidies for clean energy, continuously enhance the proportion of clean energy consumption such as natural gas, reduce the proportion of fossil fuel consumption such as coal, coking coal and oil, and control and strive to reduce the total energy consumption. These efforts will help decrease the energy consumption per unit of GDP. Third, the Chinese government should continue to improve the overall level of economic development, increase government fiscal revenue, enhance the ability to optimize the structure of energy consumption subsidies, and provide a solid foundation for improving energy technology investment and optimizing the structure of energy consumption.

This paper also suffers from some key limitations. First, limited by the data, this paper can only use the provincial panel data for empirical analysis, but cannot apply enterprise micro-data to study the impact of e-commerce development on enterprise energy consumption. Future research should obtain relevant data for an in-depth analysis into the enterprise level to further verify the theoretical research conclusions of this paper from the micro level. Second, this paper can only empirically verify the basic conclusions of the theoretical research, and the empirical analysis of the impact mechanism needs further expansion. Therefore, in future research, when relevant data are obtained, we need timely supplementation and improvement of the analysis of impact mechanism. Third, this paper only uses Chinese data for empirical analysis, and puts forth policy recommendations. In future research, after obtaining relevant data, we should use cross-border data for correlation analysis and testing to further compare and analyze the heterogeneous impact of e-commerce development on energy consumption globally.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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