APAEA

Lee, C.-C., Xing, W., & Wang, C. (2023). Impacts of Energy Security on Economic Development: Evidence From China. *Energy RESEARCH LETTERS*, *4*(3). https://doi.org/10.46557/001c.33897

Peer-reviewed research

Impacts of Energy Security on Economic Development: Evidence From China

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Keywords: Energy Security, Economic Development, China, JEL: 011 013

https://doi.org/10.46557/001c.33897

Energy RESEARCH LETTERS

Vol. 4, Issue 3, 2023

Using a panel data of 30 provinces in China from 2006 to 2018, this study evaluates the impact of energy security on economic development by employing the entropy method and panel quantile regression model. The study reveals (a) an upward trend in energy security levels, (b) regional differences in energy security levels, and (c) energy security's significant promotion effect on China's economic development, which gradually decreases with the improvement of economic development levels.

I. Introduction

The past 40 years of reforms and opening of China have caused a yearly increase in energy consumption from 141 million tons of standard coal in 2000 to 416 million tons in 2017 (Y. Chen et al., 2021; Matsumoto & Chen, 2021; Wen et al., 2022). According to BP's 2019 Energy Outlook, global energy demand will grow by about a third by 2040, driven by rising living standards, especially in India, China, and across Asia. Given the global trade frictions and conflicts since 2019, imports and exports of major energy oil could be affected by the counter globalization wave. In particular, global energy demand has declined since the outbreak of the novel coronavirus pandemic, with major energy producers Russia and OPEC announcing production cuts. However, as China's population has returned to work and production steadily progresses, demand for energy will increase as the economy recovers and life returns to normal. Energy plays an important role in China's recovery from the COVID-19 outbreak.

In 2007, the Asia Pacific Energy Research Centre (APERC) defined energy security as an economy's ability to ensure the sustainable supply of energy resources and maintain energy prices at a level that does not affect economic performance (Chi-Chuan Lee & Lee, 2022; Chien-Chiang Lee et al., 2022). This definition shows that a country's energy security has an important impact on the country's economic development (Iyke et al., 2021; Le & Nguyen, 2019). This paper uses China's provincial panel data to explore the mechanism of the impact of energy security on China's economic development through a panel quantile regression model. It is very important that China's provinces formulate energy security-related policies to promote their economic development.

II. Research Design

A. Models

A1. Empirical models

To study the impact of energy security on economic development, an extended Cobb–Douglas production function is introduced as a theoretical model based on the literature (Chi-Chuan Lee et al., 2021). The specific model is

$$Y_i = AK^{\alpha}L^{\beta}ES^{\gamma}e^{\mu} \quad (1)$$

where Y_i represents real output, ES represents energy security, K represents capital stock, L represents labor, and α, β, and γ, respectively, represent the elasticity coefficients of output for capital, labor, and energy security.

Based on the extended Cobb–Douglas production function, both sides of equation (1) are transformed into extended linear equations, to facilitate estimation. At the same time, to eliminate labor factors, the selected variables are the variables per capita. The theoretical model transformation of the panel data is as follows:

$$lnGDP_{it} = \beta_0 + \alpha_1 ES_{it} + \alpha_2 lnK_{it} + u_i + \eta_t + \varepsilon_{it} \quad (2)$$

where GDP_{it}, ES_{it}, and K_{it} represent the per capita gross domestic product, the level of energy security per capita, and the capital stock per capita, respectively; u_i denotes individual effects; η_t denotes time effects; and ε_{it} is an error term. At the same time, control variables are introduced, based on the literature. The empirical model is as follows:

$$\begin{aligned} lnGDP_{it} = \beta_0 + \alpha_1 ES_{it} + \alpha_2 lnK_{it} + \alpha_3 FD_{it} \\ + \alpha_4 lntrade_{it} + \alpha_5 FDI_{it} + u_i + \eta_t + \varepsilon_{it} \end{aligned} \quad (3)$$

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where FD_{it}, $lntrade_{it}$, and FDI_{it} represent the level of financial development, total trade per capita, and foreign direct investment per capita, respectively.

A2. Panel quantile regression models

Quantile regression is a nonparametric statistical method that can examine the relation between independent variables and the conditional quantile of dependent variables and further deduce the conditional probability distribution of dependent variables (Chien-Chiang Lee & Chen, 2021). In this paper, the quantile regression model is based on the distribution of China's provincial economic development level, to determine the impact of energy security on economic development at levels. In addition, the quantile regression model is stable in terms of extreme values, endogeneity and skewness. Because of the imbalance between provinces in China and the inadequacy of economic development of some provinces, a quantile regression model is applicable to the study of China's economic development (W. Chen & Lei, 2018). Therefore, equation (3) can be rewritten as

$$\begin{aligned} Q_{GDP_{it}}(\tau|ES_{it}) = \alpha_0^\tau + \beta_0^\tau ES_{it} + \beta_1^\tau FD_{it} \\ + \beta_2^\tau lntrade_{it} + \beta_3^\tau FDI_{it} \\ + \beta_4^\tau lnK_{it} + \varepsilon_{it}^\tau \end{aligned} \tag{4}$$

where $Q_{GDP_{it}}(\tau|ES_{it})$, $0 < \tau < 1$, represents the τ conditional quantile of GDP_{it}, and β_i^τ and α_i^τ represent the τ conditional quantiles of the coefficients and unobserved effects, respectively.

Because the equation (4) does not take into account the effect of unobserved individual heterogeneity, many scholars use mixed quantile regression panel data to resolve this problem. Therefore, equation (4) is adjusted to the following form:

$$\begin{aligned} Q_{GDP_{it}}(\tau|\alpha_i^\tau, ES_{it}) = \alpha_0^\tau + \beta_0^\tau ES_{it} + \beta_1^\tau FD_{it} \\ + \beta_2^\tau lntrade_{it} + \beta_3^\tau FDI_{it} \\ + \beta_4^\tau lnK_{it} + \varepsilon_{it}^\tau \end{aligned} \tag{5}$$

B. Indicator and data

B1. Energy security

According to the definition of energy security introduced by APERC, the energy security composite index is calculated using the entropy method based on 30 energy indicators from 2006 to 2018. At the same time, according to the different types of indicators, we subdivide energy security into four dimensions: industry construction (ES1), supply security (ES2), consumption security (ES3), and environmental impact (ES4).

B2. Data

The remaining variables are derived from the Wind database, the China Statistical Yearbook, provincial statistical yearbooks, and the website of the National Bureau of Statistics. Because of inconsistent statistical standards across different regions and a lack of relevant data, a sample of 30 provinces in China from 2006 to 2018, excluding Hong Kong, Macau, Taiwan, and Tibet, was used in this paper. Table 1 presents the variable names and calculation methods.

III. Empirical Results

A. Empirical analysis

In this paper, we collected energy-related data from 30 provinces in China from 2006 to 2018, and used the entropy method to estimate the energy security levels at the provincial level (Fang & Yu, 2016). The results show that, in 2006, the energy security level at the provincial level in China varied from high to low in the west and was strong in the north and weak in the south (Cheng et al., 2021). However, compared with 2006, the energy security level of these provinces has improved in 2018, especially the energy security level of the provinces in the central region has improved significantly. In addition, the paper adopts the ordinary least squares (OLS) method, a fixed effects model, and panel quantile regression models to identify the effects of provincial energy security on economic development.

A1. Empirical results analysis

Table 2 reports the estimation results of the impact of energy security on economic development (Chu & Hoang, 2021). Columns (1) and (2) utilize OLS and the fixed effects model, respectively (see Zhu et al., 2016). Columns (3) to (6) utilize the fixed effects model to estimate the impact of the four subdimensions of energy security on economic development, including industry construction, supply security, consumption security, and environmental impact.

The empirical results of columns (1) and (2) in Table 2 show that, whether using the OLS or the fixed effects model estimation, energy security can safely promote the economic development of China's provinces. A possible reason is that the greater the energy security, the stronger the energy security capacity and the higher the efficiency of energy consumption, which can lead to sufficient energy for economic development and thus promote economic development.

The results in columns (3) to (6) of Table 3 show that the different subdimensions of energy security have different impacts on economic development. Industry construction, consumption safety, and environmental impact have a positive role in promoting economic development. A possible reason is that large-scale industrial infrastructure construction helps to drive fixed asset investment and thus promote economic development; increasing energy consumption helps enterprises obtain more resource factors for production, thereby promoting economic development; and strengthening environmental regulation helps strengthen technological innovation, improve production efficiency, and promote economic development.

A2. Panel quantile regression results

Table 3 shows the panel quantile regression results of the impact of energy security on economic development. The empirical results show that, from the 10th to the 90th quantiles, the marginal effect of energy security on eco-

Table 1. Definition of variables.

Variables	Formula	Algorithm
GDP	Real GDP / resident population	Natural logarithms
ES	Energy security composite index	Entropy method
K	Capital stock per capita = capital stock / resident population	Natural logarithms
Trade	Total trade per capita = total import / export trade / resident population	Natural logarithms
FDI	FDI per capita = FDI / resident population	Natural logarithms
FD	Financial development level = financial added value / GDP	/

Note: The table shows the definition/calculation of variables.

Table 2. Linear benchmark model results.

Model	(1)	(2)	(3)	(4)	(5)	(6)
Method	OLS	FE	FE	FE	FE	FE
ES	0.931*** (4.47)	0.728*** (3.66)				
ES1			0.115 (0.34)			
ES2				-0.777*** (-2.68)		
ES3					4.244*** (9.86)	
ES4						2.101*** (4.19)
FDI	0.074***	0.072***	0.075***	0.077***	0.064***	0.065***
	(4.35)	(5.44)	(5.51)	(5.77)	(5.42)	(4.91)
Trade	0.072***	0.024***	0.027***	0.026***	0.017***	0.023***
	(7.41)	(4.09)	(4.44)	(4.40)	(3.24)	(3.87)
K	0.681***	0.459***	0.432***	0.425***	0.528***	0.412***
	(34.68)	(14.67)	(13.71)	(13.89)	(18.22)	(13.57)
FD	-0.415	-0.996**	-1.074**	-1.100***	-0.635*	-1.133***
	(-1.28)	(-2.42)	(-2.56)	(-2.65)	(-1.70)	(-2.77)
_cons	5.602***	6.608***	6.960***	7.060***	6.446***	6.859***
	(55.89)	(41.42)	(47.17)	(56.22)	(52.70)	(55.04)
R-squared	0.949	0.981	0.980	0.981	0.985	0.981
Hausman test(P-value)		30.49*** (0.000)	29.89*** (0.000)	31.22*** (0.000)	23.80*** (0.000)	41.98*** (0.000)
Provincial FE		Yes	Yes	Yes	Yes	Yes
Year FE		Yes	Yes	Yes	Yes	Yes
N	390	390	390	390	390	390

Note: OLS and FE denote, respectively, ordinary least squares and fixed-effect estimators. *t*-statistics are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

nomic development decreases with improvements of the provincial economic level. This means that the impact of energy security on economic development has a nonlinear relationship with economic levels.

IV. Conclusion

This paper constructs an empirical model of the impact of China's energy security on economic development by expanding the Cobb–Douglas production function. The entropy method is used to evaluate the energy security levels of 30 provinces in China from 2006 to 2018. A panel quantile regression model is then used to analyze the nonlinear impact of energy security on economic development. The results show the following: (1) The level of energy security has an upward trend, with regional differences, from high in the west to low in the east, strong in the north, and weak in the south. (2) The overall energy security level has the effect of promoting China's economic development, and this effect gradually decreases with improvements in economic development levels. (3) Different subdimensions of energy security have different impacts on economic development. Among these impacts, industry construction, consumption safety, and environmental impact gave a positive role in promoting economic development.

Table 3. Panel Quantile Regression Model Results.

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Quantile	10th	20th	30th	40th	50th	60th	70th	80th	90th
ES	2.250*** (3.75)	2.056*** (4.21)	1.875*** (4.74)	1.680*** (5.29)	1.443*** (5.22)	1.322*** (4.62)	1.190*** (3.68)	1.080*** (2.94)	0.974** (2.33)
FDI	0.045 (1.13)	0.047 (1.43)	0.048* (1.83)	0.049** (2.37)	0.051*** (2.82)	0.052*** (2.73)	0.052** (2.45)	0.053** (2.17)	0.054* (1.93)
Trade	0.026 (1.53)	0.024* (1.77)	0.023** (2.07)	0.021** (2.43)	0.019** (2.56)	0.018** (2.32)	0.017* (1.93)	0.017 (1.61)	0.016 (1.34)
K	0.819*** (15.58)	0.818*** (19.17)	0.818*** (23.80)	0.817*** (30.01)	0.817*** (34.51)	0.816*** (32.85)	0.816*** (28.95)	0.816*** (25.37)	0.816*** (22.23)
FD	-0.627 (-0.59)	-0.596 (-0.69)	-0.568 (-0.82)	-0.538 (-0.98)	-0.501 (-1.05)	-0.482 (-0.96)	-0.461 (-0.81)	-0.444 (-0.69)	-0.427 (-0.58)
Provincial FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	390	390	390	390	390	390	390	390	390

Note: The table shows the panel quantile regression estimates. *t*-statistics are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

It is therefore suggested that China should choose an energy consumption model with economy, environmental protection, and sustainability as core principles; increase investment in energy security technological innovation; dynamically adjust energy production and supply from inside and outside in a multidimensional way; and continuously strengthen energy security and promote economic development.

Acknowledgment

This research was supported by the Social Science Foundation of Jiangxi Province of China with financial support from Grant No. 21JL02.

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