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The Impact of High-Quality Energy Development and Technological Innovation on the Real Economy of the Yangtze River Economic Belt in China: A Spatial Economic and Threshold Effect Analysis

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Abstract: The sustainable economic development of the Yangtze River Economic Belt is a significant part of China's regional development strategy. The article selects panel data from 11 provinces of the region from 2004 to 2020 and constructs a spatial economic model and a threshold effect model to investigate the impact of energy development and technological innovation on the real economy of this region. The result indicates that technological innovation plays a significantly beneficial role in supporting the development of the local real economy, while its spatial spillover effect to neighboring provinces is not significant. Energy development has a significant negative impact on both the local real economy and that of the neighboring provinces. Such impact is shaped by the threshold effect of the level of technological innovation.

Keywords: technological innovation; energy development; real economy; spatial economics

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1. Introduction

The COVID-19 pandemic has severely disrupted financial markets and the real economy worldwide to an unprecedented degree. In tackling COVID-19, China prioritized maintaining the vitality of the real economy. Despite an economic rebound from COVID-19, the real economy is at a crossroads. A new paradigm of "high-quality development" has become the policy underpinning China's economic recovery. In essence, this emphasizes a sustainable and resilient real economy which can serve as the engine for new development, as well as helping to achieve the country's carbon peak and neutrality goals, despite COVID-induced growth challenges.

Competitive cities play a critical role in global value chains (GVCs) and vice versa. The "network" effects of cities comprise the provision of adequate infrastructure, the scale of employment, and the talented skilled workforce, which in turn provide a vehicle for cities to integrate into GVCs [1]. Many cities are embedded in elongated multi-city corridors and wider sub-national regions. Chinese cities have been raising their economic intercity connectivity both at sub-national and cross-border levels, and the increasingly closer connections between Chinese cities and other world cities imply the importance of the development of China's regional real economy [2,3]. Large corporations are further extending their economic power beyond their geographic location to shift the geographic pattern of cities [4]. The Yangtze River Economic Belt (hereinafter "the Belt"), established by the Chinese Central Government, has been a significant part of China's regional economic development strategy since 2015. As shown in Figure 1, it encompasses eleven provinces and municipalities, including Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan and Guizhou, accounting for 46% of the country's GDP in

2020. The Belt is home to many of the country's free trade zones and the main convergence zone of the Belt and Road in China. The spatial agglomeration of this region has attracted research attention from perspectives of infrastructures, industrial eco-efficiency and coordinated industrial development [5,6]. In 2020, the Chinese president called for the comprehensive development of the Belt. Xi also pointed out that the focus should be on the real economy, while seeking breakthroughs in key technologies and innovation to make it a pioneer in green growth, "dual circulation" development, and high-quality development [7]. Now the Belt region is set to be amongst the driving forces spearheading the country's highest-quality development in a new era. Therefore, it is important to investigate the impact of technological innovation and energy development on the real economy of the Belt region. This will be of great significance in improving relevant regulatory policies that facilitate high-quality development in the region.

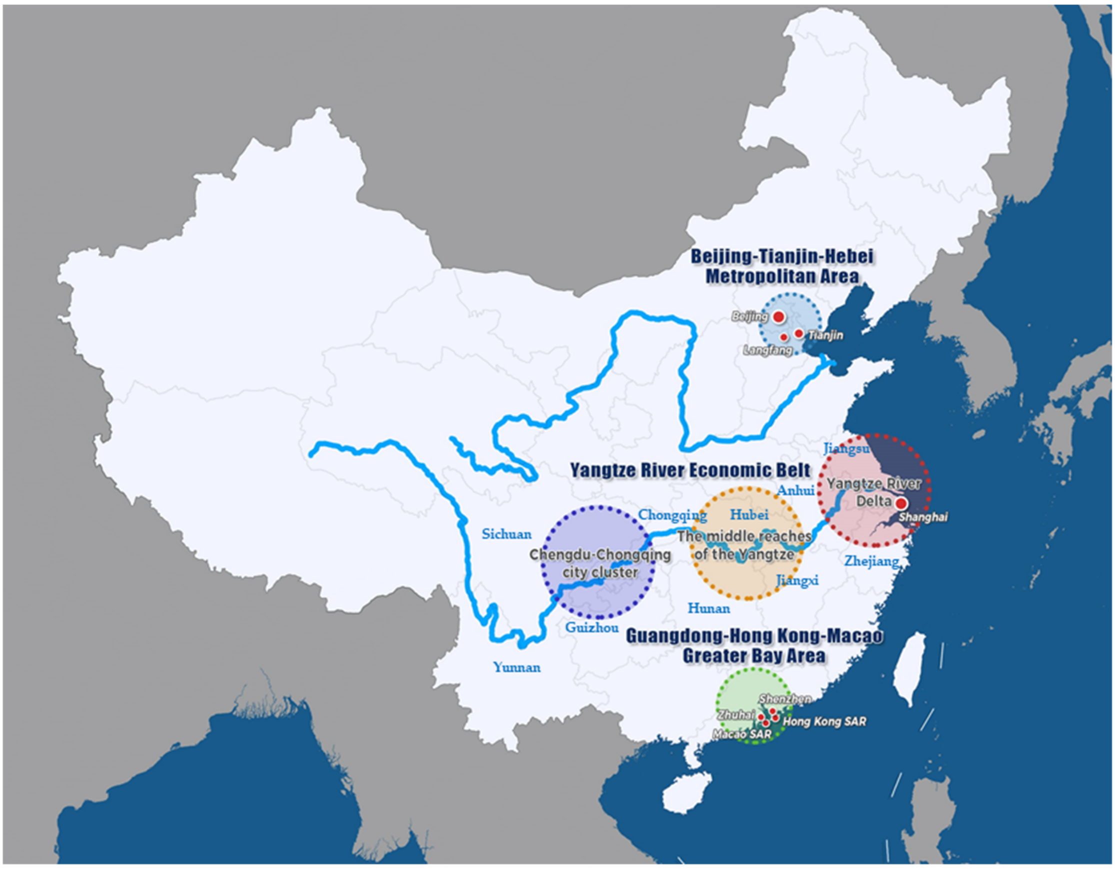

Figure 1. The map of the Yangtze River Economic Belt. Source: CGTN, accessed at: https://news.cgtn.com/news/2020-11-09/Shanghai-s-leading-role-in-the-Yangtze-River-Economic-Belt-Vhdapg45Pi/index.html, accessed on 11 January 2023.

Technological innovation is the driving force for the long-term sustainable development of an economy. Over the past decade, China has emerged as a technology powerhouse. However, the technology industry in China is still rife with bottlenecks. The lack of core and knowledge-intensive technologies is more pronounced due to the contextual background of the US–China trade war and supply chain disruptions [8,9]. Cities have always been associated with transformative activities and novel initiatives to foster technological progress and creative economies [10]. Some cities can harness most of their potential and do more with their resources than others by introducing information technologies to intelligent transportation, healthcare, and financial services [11–13]. Case studies on Chinese innovation hubs focusing on different innovative sectors and development paradigms have been discussed [14,15]. The concentration of innovation activities in major cities and innovation hubs can lead to knowledge spillover and the spatial dynamics of innovation [16–19]. Strong spillover effects are found in both the input and output processes of regional innovation [20]. Such regional spillover effects of innovation have also been observed in China to figure out how they impact carbon emission, foreign direct investment, and overall high-quality development [21–23].

The energy sector is a key component of industrial development. It fuels the economy and provides the necessary energy infrastructure—from resource extraction to the technologies producing energy carriers and the end-use equipment to deliver the required energy services [24,25]-to other industrial sectors. The fuels relied on, however, are also a key source of greenhouse gas emissions. Energy security in energy transitions received both political and scholarly attention [26–28]. The energy sector is growing rapidly in emerging markets and plays an important role in their cities [4,29]. The spatial distribution of energy use and economic growth focusing on the link between them is identified in different regions of the world [30], so it is important to decipher the energy and economic growth linkages for the Chinese economy, as it is predicted that energy demand in the world will be increased. As the world's largest greenhouse-gas emitter, China announced its new objective to reach peak CO_2 emissions before 2030 and to achieve carbon neutrality by 2060. To reach these targets, more efficient technologies are required for the provision of sustainable energy services, and a more efficient energy consumption model should be adopted.

The study uses two different models, the spatial Durbin model (SDM) with fixed effects methods, and the threshold model, in order to cross-check the results and strengthen the robustness of the findings. This study aims to contribute further evidence regarding the impact mechanisms of technological innovation and energy development on the sustainable real economy. It also aims to contribute to the formulation of policies for the sustainable and high-quality development of the region, by providing a reference point for the region's policymakers to develop regulations that cater to the needs of the regions in this area. The novelty of this study lies in the combined analysis of two driving forces of the real economy—technological innovation and energy development—into the spatial models, so as to identify the impact and synergies of both, and linking this with the development of the real economy.

After a review of the relevant literature in Section 2, this article continues, in Section 3, to discuss relevant data in the context of the research methodology and methods. Section 4 analyzes the results from the SDM that determines the relationship between technological innovation, energy development, and the sustainable real economy in the Belt region. The article sets out the discussions of findings and discusses the policy implications and areas for future research in Section 5. The article draws the main conclusions in Section 6.

2. Literature Review

Affordable and clean energy is one of the 17 Sustainable Development Goals established by the United Nations. Energy development is an important indicator for ensuring sustainable development. However, fossil fuels, including oil and coal, still account for more than half of global energy consumption. Many scholars have studied the interrelation between energy development and economic growth at the national level with different approaches. Azad et al. [31] use a production function approach to explain the interrelationship between renewable and non-renewable energy consumption, CO_2 emissions, and economic growth in Australia. Armeanu et al. [32] investigated the influence and causal relationship between renewable energy and sustainable economic growth of the European Union (EU)-28 countries with panel data fixed effects regression models. Liu [33] examined the relationship between primary energy consumption and real GDP in China, India, Japan, and South Korea with the bootstrap panel Granger causality method. Alper and Oguz [34] investigated the causality among economic growth, renewable energy consumption, capital, and labor for new EU member countries by using the asymmetric causality test approach and autoregressive distributed lag approach. The same approach has also been used by

Sari et al. [35] on energy consumption and industrial production in the United States. Apergis and Payne [36] tested the relationship between renewable/non-renewable energy consumption and economic growth for 80 countries with a panel error correction model. The literature has extensively examined energy consumption and economic growth, yet no consensus has been expressed. Some scholars suggest a unidirectional causality (either positive or negative), within a timeframe, in certain countries [37,38], while others find bidirectional relationships [39]. There have also been many scholars providing support for no causality between renewable energy consumption and economic growth in different countries [40–43]. The literature also finds that other factors, for instance, price and energy investment, are central to understanding the relationship [44,45]. Some research has also suggested the differences between developed nations and emerging markets regarding the linkages between their economic performance and energy demand [30,46].

The contribution of technological innovation to higher productivity and greater output, in other words, economic growth, has long been recognized in the literature from descriptive to empirical economic literature. Input measures, such as R&D expenditures or innovation outcomes such as patents, are often used as a measurement for innovation in the Cobb-Douglas production function [47–49]. Recent research starts to investigate the spatial spillovers of regional innovation. Balash et al. [50] found that the GDP per capita growth rate is dependent on the growth rate of expenditure on technological innovation in neighboring regions and the effect of their influence in Russia. Song and Zhang [20] assessed whether and how the effects of spatial spillovers contribute to regional innovation growth in China with SDM and revealed strong spillover effects in both the input and output processes of regional innovation. Scholars also found that innovation is fundamentally linked to the territory. In many cases, innovation has impacts elsewhere. Concentration of innovation activities can lead to knowledge spillover and spatial dynamics of innovation [16–18]. In some other cases, local development is not necessarily linked to innovation [51].

In sum, studies on the impact of energy and technology innovation on the real economy have been largely muted on the synergies of two factors that can have a significant impact. To fill in this gap, this study incorporates the development of the real economy, technological innovation, and energy development into a research framework, and analyzes the spatial effects of factors relating to the high-quality development of the real economy within the Belt region.

3. Materials and Methods

3.1. Data Description

The eleven provinces and municipalities alongside the Belt are selected for empirical analysis and the sample interval is between 2004 and 2020. The data used are taken from the Statistical Yearbooks of China (National Bureau of Statistics of China). Some of the missing data are obtained from provincial statistical yearbooks. Linear interpolation is used to complement some missing data in the samples. The descriptive statistics for the numerical variables are shown in Table 1:

Table 1. Descriptive Statistics for the Numerical Variables.

Variables	Symbol	Observed Value	Mean	Standard Deviation	Minimum	Maximum
Development of real economy	*LNRE*	187	9.5678	0.8163	7.3473	11.3657
Technological innovation	*LNTI*	187	9.9523	1.4832	6.6026	13.1204
Energy development	*ED*	187	0.3459	0.1243	0.1539	0.7434
Financial development	*LNFD*	187	1.6512	0.4911	0.5040	2.9187
Fixed investment	*LNFI*	187	4.1444	0.4249	1.8290	4.7616
Exports	*LNEX*	187	2.4186	0.9700	0.6678	4.4722
Consumption level	*LNCL*	187	3.6491	0.1556	3.3223	3.9709

As shown in Table 2, the mean value of the variables relating to the development of the real economy, technological innovation, and energy development are 9.5678, 9.9523 and 0.3459, respectively. The standard deviations for these three variables stand at 0.8163, 1.4832 and 0.1243, respectively. This suggests that the development of the three variables varies significantly across the provinces. The same distributive properties have also been observed across other variables.

Table 2. Evaluation Index of Energy Development.

Indicators	Secondary Indicators	Unit	Attribute	Weight
Energy Supply (0.2532)	Energy consumption per capita	Tons of standard coal	+	0.2532
Energy Consumption (0.6092)	Coal	Thousand tons	−	0.0611
	Electricity	Billion kWh	+	0.2510
	Gas	Billion cubic meters	+	0.2971
Energy Efficiency (0.1376)	Energy consumption per unit of GDP	Tons of standard coal/1000 Yuan	−	0.0705
	Electricity consumption per unit of GDP	KWh/Yuan	−	0.0671

Note: "+" represents a positive indicator and "−" represents a negative indicator. Values in parentheses for each indicator are weights.

3.2. Model Specification

3.2.1. Spatial Durbin Model

In spatial econometrics, the most commonly used methods developed to handle spatial effects are the spatial autoregressive (SAR) model, the spatial error model (SEM), and the spatial Durbin model (SDM). The SDM considers the spatial correlation between independent and dependent variables and provides accurate estimates of direct impacts, even in the case of misspecification. In this regard, the SDM is employed to investigate the impact of technological innovation and energy development on the real economy in the Belt region. Our SDM is specified as follows:

$$\begin{aligned} \mathrm{LNDRE_{i,t}} = {} & \alpha_0+\alpha_1\mathrm{LNTI_{i,t}}+\alpha_2\mathrm{ED_{i,t}}+\alpha_3\mathrm{Col_{i,t}}+\alpha_4\mathrm{W_{ij}}*\mathrm{LNTI_{i,t}} \\ & +\alpha_5\mathrm{W_{ij}}*\mathrm{ED_{i,t}}+\alpha_6\mathrm{W_{ij}}*\mathrm{Col_{i,t}}+\mu_i+v_t+\varepsilon_{i,t} \end{aligned} \tag{1}$$

LNDRE and LNTI are the natural logarithmic forms for the development of the real economy and technological innovation, and ED stands for energy development. Col denotes control variables, which include LNFD, LNFI, LNEX and LNCL. α_i and β_i represent coefficients to be estimated, μ_i represents spatial fixed effects; v_t represents time fixed effects; ε_{it} is used for random errors and W_{ij} is used for the spatial weights matrix. This study uses a spatial weights matrix based on economic distance ($w1$) for correlation tests and a weight matrix based on geographic distance ($w2$) for robust tests. The specific forms are:

$$\mathrm{w1_{ij}} = \begin{cases} 1/\left|\overline{y_i}-\overline{y_j}\right| \ \&i \neq j \\ 0 \ \&i = j \end{cases} \tag{2}$$

$$\mathrm{w2_{ij}} = \begin{cases} 1/d_{ij} \ \&i \neq j \\ 0 \ \&i = j \end{cases} \tag{3}$$

3.2.2. Threshold Model

The threshold model is used to analyze the degree of influence between variable changes after a threshold variable reaches a certain threshold value. To further investigate the impact of energy development on the real economy under different levels of technological innovation, the equation of the threshold model with LNTI as the threshold variable is used as follows:

$$\mathrm{LNDRE_{it}} = \varphi_0 + \beta_1 \mathrm{ED_{it}} \times \mathrm{I}(\mathrm{LNTI}_{it} \leq \gamma) + \varphi_2 \mathrm{ED_{it}} \times \mathrm{I}(\mathrm{LNTI}_{it} > \gamma) + \varphi_3 \mathrm{Col_{it}} + \varepsilon_{it} \quad (4)$$

where φ_i is the coefficient, γ is the threshold value, ε_{it} is the error term, $\mathrm{I}(\cdot)$ is the indicator function, taking value 1 if the condition inside is satisfied and 0 otherwise.

4. Empirical Analysis and Results

4.1. Variable Selection

4.1.1. Core Variables

Core variables consist of explained variables and explanatory variables. In this study, the explained variable is the development of real economy (DRE), and the explanatory variables are technological innovation (TI) and energy development (ED). We use adjusted GDP, excluding financial and real estate sectors, as the indicator for the explained variable (DRE).

The number of patents is used as an indication of technological innovation (TI). DRE and TI are introduced into the model in the form of their natural logarithms. When it comes to the indicators for energy development (ED), a comprehensive evaluation index with three indicators—energy supply, energy consumption, and energy efficiency—is constructed, drawing on existing literature (Table 2). The entropy method is used to assign weights to various indicators to measure the energy development status of the Yangtze River Economic Zone.

Table 2 shows that energy consumption has the highest weight in the index (0.6092), followed by energy supply, and then energy efficiency (0.2532, and 0.1376, respectively). Of all the secondary indicators, gas consumption accounts for the highest proportion. This indicates a transformation of energy consumption in the Yangtze River Economic Zone from traditional coal-based fuels to new energy. Such changes also lead to achieving greater energy efficiency. The existing literature also suggests that the level of energy efficiency in China is slightly higher than the average for developed economies [52].

4.1.2. Control Variables

The development of the real economy is impacted by multiple factors, notably financial development (FD), fixed investment (FI), exports (EX), and consumption level (CL). The growth of finance and fixed investment can foster funding provision in the real economy. In addition, strong exports and the expansion of consumption stimulate growth in the real economy. In this regard, 'financial development', 'fixed investment', 'exports' and 'consumption level' are selected as control variables for the analysis. When it comes to the control variables, the ratios comparing the added value of the financial sector to GDP (%), total fixed assets to GDP (%), total net exports, and total retail sales of consumer goods to GDP (%) are selected as specific indicators for each control variable.

To remove heteroscedasticity, each control variable is introduced into the model in the form of its natural logarithm. The higher the absolute value, the higher the level of the corresponding variable.

4.2. Selection of Spatial Durbin Model

4.2.1. Spatial Autocorrelation Test

In spatial econometrics, a commonly used test of spatial autocorrelation is the global Moran Index (Moran's I). I > 0 indicates positive spatial autocorrelation, and the city has a strong positive correlation with its neighboring cities, whereas when I < 0, it indicates a negative autocorrelation. I = 0 means spatial irrelevance. Using Stata 15.0 to calculate Moran's I of the development of the real economy of the Belt (LNDRE) from 2004 to 2020, the results are shown below:

Table 3 shows that the global Moran Index relating to the development of the real economy of the Belt from 2004 to 2020 is positive. This result shows that there is spatial autocorrelation in the development of the real economy of the region, and that the development of the real economy in neighboring provinces and cities are interconnected and can be influenced by each other. Therefore, it is appropriate to construct a spatial econometric model to empirically analyze the effects of technological innovation and energy development on the real economy.

Table 3. Moran Index and the corresponding Z test statistics of the Development of the Real Economy of the Belt (*LNDRE*).

Year	I	Z	Year	I	Z
2004	0.266 **	1.775	2013	0.188 *	1.401
2005	0.273 **	1.805	2014	0.187 *	1.394
2006	0.272 **	1.801	2015	0.192 *	1.423
2007	0.266 **	1.770	2016	0.203 *	1.479
2008	0.263 **	1.763	2017	0.202 *	1.484
2009	0.243 **	1.671	2018	0.160	1.274
2010	0.235 *	1.627	2019	0.144	1.190

Note: **, and * indicate significance at the level of 5%, and 10% respectively.

4.2.2. Model Selection Test

The spatial model consists of the spatial error model (SEM), the spatial lag model (SLM) and the spatial Durbin model (SDM). The construction of a specific spatial model requires a series of tests, and the selection is based on the test results. The Lagrange multiplier (LM) test is used to determine the specific type of model, and the results are all significant at the 10% test level, indicating that SDM should be selected. The Hausman test method is then used to help choose between a fixed effects model and a random effects model. The test result rejected the null hypothesis at the 1% significance level, suggesting within a timeframe that a fixed effects model should be selected. In addition, the Wald test and the likelihood ratio (LR) test are used to decide whether SDM is the best model to analyze the data at hand. Both tests reject the null hypothesis at 5% significance level, which once again, shows that SDM is more suitable than SLM or SEM. Furthermore, the LR test is used to determine whether to choose a space-fixed effects model, a time-fixed effects model, or a two-way fixed effects model. The test results support both the space-fixed effects model and the time-fixed effects model. Based on the aforementioned tests, we can determine the use of a spatial Durbin model with a two-way fixed effects model in both space and time. The test results are shown in Table 4:

Table 4. Test Results for Selection of Relevant Models.

Tests	Null Hypothesis	Significance	Result
LM Test	SEM Model	3.650 *	Reject
	SEM Model (Robust)	3.404 *	
	SLM Model	3.414 *	
	SLM Model (Robust)	3.168 *	
Hausman Test	Random effect	24.09 ***	Reject
Wald Test	SEM/SAR perform better than SDM	17.07 ***	Reject
LR Test	SEM performs better than SDM	16.32 **	Reject
	SLM performs better than SDM	237.25 ***	Reject
	Space-fixed effect performs better than two-way fixed effect	105.92 ***	Reject
	Time-fixed effect performs better than two-way fixed effect	363.42 ***	Reject

Note: ***, **, and * indicate significance at the level of 1%, 5%, and 10% respectively.

4.3. Results and Discussion

Based on the above tests, we used Stata 15.0 to estimate Equation (1) and the results are shown in Table 5.

Table 5. Test Results for the Spatial Durbin Model.

Variable	Coefficients		Variable	Coefficients	
	w1	w2		w1	w2
LNTI	0.1205 ***	0.1562 ***	*W*LNGTI*	0.0538	0.0901
	(6.51)	(9.63)		(1.58)	(1.17)
ED	−0.3101 ***	−0.2291 **	*W*ED*	−0.6113 **	−0.6998 *
	(−2.84)	(−1.98)		(−2.26)	(−1.75)
LNFD	−0.2671 ***	−0.2451 ***	*W*LNFD*	−0.2219 ***	−0.0410
	(−8.02)	(−6.26)		(−3.34)	(−0.24)
LNFI	0.1149 ***	0.1021 ***	*W*LNFI*	0.1436 ***	0.4456 ***
	(6.22)	(5.29)		(3.03)	(4.77)
LNEX	0.0988 ***	0.0486 ***	*W*LNEX*	0.1610 ***	0.3230 ***
	(5.30)	(2.61)		(4.45)	(5.17)
LNCL	0.1164	−0.0316	*W*LNCL*	0.2135	−0.6247 *
	(1.53)	(−0.45)		(1.48)	(−1.73)
R^2	0.7046	0.7919	α^2	0.0029 ***	0.0025 ***

Note: Z-scores in parentheses. ***, **, and * indicate significance at the level of 1%, 5%, and 10% respectively.

When the weight matrix of the economic distance (w1) and the weight matrix of the geographic distance (w2) are introduced into the model, the goodness-of-fit for both w1 and w2 are greater than 0.7, indicating that the models selected fit the observed data. Specifically, the coefficients of technological innovation are 0.1205 and 0.1562, both significant at the significance level of 1%. These results show that technological innovation has a significant positive impact on the development of the real economy. An important indicator of technological innovation is the number of patents, utility models patents, and industrial designs, which protect the technical aspects of an invention as well as the appearance or aesthetic features of a technological product. To be more specific, the application of patents can fundamentally change the production methods or models of an enterprise to improve production efficiency. The application of utility models can improve the production process and upgrade product performance. Industrial designs can improve the aesthetic features of a product, consequently stimulating consumers' desire to purchase. Therefore, the implementation of such innovations is directly related to production and will greatly enhance production efficiency. This, in turn, can increase the sales volume of products, and support the real economy.

Under w1 and w2, the coefficients of the impact of energy development on the real economy in the Belt region are −0.3101 and −0.2291, respectively, which are both significant at the 5% level. This result shows that energy development has a significant negative impact on the development of the real economy. Energy development consists of energy consumption per capita, total energy consumption, as well as energy efficiency. The bigger the value of energy development, the higher the energy consumption per capita and the greater the energy consumption per unit of GDP. In other words, the bigger the energy development value, the lower the energy efficiency. When the industrial level of the real economy upgrades, energy consumption should gradually decrease. On the other hand, the lower the industrial level of the real economy, with less advanced technologies being applied, the higher the energy consumption will be. All the while, energy serves as an important input for industries in the real economy. Therefore, the high-quality development of energy sectors can directly affect the development of the real economy.

The coefficients of W*LNTI are positive in both models, but neither is significant, indicating that the technological innovation of a province does not significantly impact the development of the real economy in its neighboring province(s). In other words, technology companies tend to co-locate and cluster near each other to generate a technology hub, thus having less impact on the innovation activities of its neighboring province(s). This can be explained partly by the competitive and knowledge-intensive nature of innovative activities, which leads to industrial spatial agglomerations and clusters that have received strong research attention. Consistent with the existing literature, the positive spillover effects of technological innovation have not been identified in the Belt region. This result also suggests that the linkages between supply chains of the Belt are not yet strong, and that the coordination and integration of the supply chains within the region are weak.

The two coefficients of W*ED are both negative and are both significant at the significance level of 10%. This suggests that energy development in one province has a significant negative effect on the development of the real economy in its neighboring province(s). Most of the energy used in the region is not renewable, and the supply is limited. The more energy consumption in one place, the fewer energy resources are left to allocate to another place. This leads to competition for exhaustible energy among different provinces. In this regard, energy development has a significant negative spatial spillover effect.

The remaining control variables have different degrees of influence on the development of the real economy, but they are not the focus of this article and will not be described in detail.

4.4. Testing for Threshold Effects

To further investigate the impact of energy development on the real economy under different levels of technological innovation, technological innovation (LNTI) is introduced as a threshold variable in Equation (2) with set seed 1000 and grid 400. The estimation results are shown in Table 6.

Table 6. Estimation Results of the Threshold Model.

Variable		Coefficients	F Value/*t* Value	*p* Value
LNTI	Threshold value γ	9.3953 ***	58.4 (F value)	0.001
ED	$(LNTI \leq \gamma)$	0.3875	0.53 (*t* value)	0.608
	$(LNTI > \gamma)$	1.5539 *	1.82 (*t* value)	0.098
C		2.8881 *	2.04 (*t* value)	0.068

Note: *** and * indicate significance at the level of 1% and 10% respectively.

The threshold value stands at 9.3953, at the significance level of 1%. When the level of technological innovation is lower than the threshold value 9.3953, the impact of energy development on the real economy is not significant. Equally, the coefficient of the impact is 0.3875. When the level of technological innovation is above the threshold value, the facilitative effect of energy development on the development of the real economy becomes significant. The coefficient of impact is 1.5539, passing the 10% level significance test. In addition, the goodness-of-fit result is 0.8705, suggesting the appropriate fit of the observations.

The above analysis suggests that the threshold effect of energy development on the real economy is caused by the level of technological innovation. When the level of technological innovation is high, the positive impact of energy development on the development of the real economy becomes substantial and energy serves as a facilitative tool for the further development of the real economy. Conversely, when the level of technological innovation is low, the impact of energy development on the real economy is weakened. This sheds light on the impact and synergies of energy and technology on the real economy. The level of technology applied affects the quality of output. Energy inputs will be optimized with the application of high technology, thus also having positive implications for the development of the real economy. Based on the observed data, the overall level of technological innovation (LNTI) of the Belt is 9.9523—this is higher than the threshold value—indicating that, at the current level, the energy development of the Belt region can achieve a further considerable level of positive impact on the development of the real economy.

However, the estimation results of the SDM model suggest that energy development has a significant negative impact on the development of the real economy with coefficients −0.3101 and −0.2291 (see Table 5 above). The results are not consistent under the SDM and the threshold model. Such inconsistency indicates that under the status quo, a positive effect of energy development on the real economy is not observable. The role energy development plays in the real economy could be constrained by other factors.

5. Discussion

The results of this study could be useful to policymakers and authorities that are engaged in growth and development policies in the Belt region, at a national level, and also in other countries for international comparisons.

Firstly, the results of the spatial Durbin model indicate that technological innovation has a significant positive impact on the development of the real economy. The existing literature using different models, variables, and countries/regions as cases came to the same conclusion as this study. For example, based on a sample of 58 countries, Hasan and Tucci [53] find that countries hosting firms with higher-quality patents also have higher economic growth and those countries that increase the level of patenting also witness a concomitant increase in economic growth. Using an ARDL model, Sohag et al. [54] find that technological innovation and diffusion support overall economic growth. Torres-Preciado et al. [55] use the spatial Durbin model with the SAR and SEM model and find that technological innovation has a positive effect on Mexico's regional economic growth.

Secondly, our study finds that energy development has a significant negative impact on the development of the real economy. In this study, according to our construction for the variable of energy development, the bigger the value of energy development, the higher the energy consumption per capita and the greater the energy consumption per unit of GDP and the lower the energy efficiency. This result is consistent with most of the existing literature that studies other cities, regions, and countries. For example, Akalpler and Hove [56] find that in the short term, real gross domestic product per capita for the Indian economy could be affected by energy consumption and carbon emissions. However, Omri [57] conducts an extensive review of the literature on the nexus between economic growth and four types of energy consumption and finds that there is no consensus neither on the existence nor on the direction of causality between energy consumption and economic growth.

Interestingly, the threshold model results indicate that the effects of energy development on the real economy could be influenced by the level of technological innovation, that is, the higher the technological innovation is, the more significant the impacts of energy development on the real economy are. This result confirms the findings of previous studies that technological innovation boosts energy efficiency in the long run [54].

Finally, our study finds that the spillover effects of technological innovation are not statistically significant, which is not consistent with some of the existing literature. For example, Tientao et al. [58] find that technological spillovers strongly impact productivity growth in 107 countries using the spatial Durbin model and a constructed TFP growth model. However, our results are consistent with existing literature that specifically study the Belt region, and the weak spillover effects can be explained by the competitive and knowledge-intensive nature of innovative activities in a certain area of China. Using the spatial Durbin model to analyze a sample of 30 provinces in China, Cao et al. [59] find that green technology innovation has heterogeneous spatial effects in different samples.

The results also shine a light on policymakers in countries that are facing the same development challenges, and for emerging economies boosting their economic development of different regions by transforming their energy sector and fostering their technological innovation. Especially, the study finds that when the level of technological innovation is high, the positive impact of energy development on the development of the real economy becomes substantial and energy development could facilitate economic development. Therefore, transforming the energy sector into a more sustainable, high-quality, and green sector should be based on the technological development of the countries or regions, and more efforts including more investment in R&D, implementing favorable policies for enterprises to innovate, and putting more emphasis on education and cultivating talents should be made.

Several future research directions can be addressed. Sustainable development of the real economy is complex, but due to the limiting themes and methodology in this study, many influencing factors were not included in the analysis. Especially, in an era of global economic integration and uncertainties caused by the COVID-19 pandemic, the real economy could be further influenced by global economic conditions and international logistics and policies. The analysis could be further improved by adding other variables that could have an impact on the real economy in terms of regional development, global economic conditions and financial markets [60], regulations and governance, and logistics and industry 4.0 [61,62], intensive population urbanization [63], and dual circulation policy [64] in order to understand the development of real economies and explore the rapid innovation and development of digital economy more thoroughly. Considering the increasing uncertainties and various economic shocks, innovative high-dimension models such as a global autoregressive model [65] could be implemented with an extended time span, more influencing factors, and more regions or countries, in order to explore the factors and mechanisms that might affect sustainable development in the real economy and to evaluate the impacts of shocks from different factors on the real economy.

6. Conclusions

The empirical analysis with the spatial Durbin model and the threshold effect model on the impact of technological innovation and energy development on the real economy of the region based on data from the 11 provinces along the Belt, for the period 2004 to 2020, leads to the following conclusions.

Firstly, both technological innovation and energy development have a significant impact on the development of the real economy. Technological innovation has a significant positive impact on the real economy, while energy development has a significant negative impact on the sustainable real economy. Technological innovation, through its main forms of patents and utility models, can be directly applied to production and it can play a beneficial role in improving output efficiency, upgrading industrial structure, and thus supporting the development of the real economy. Energy is an indispensable resource for the development of the real economy. Only with the support of high technology can energy development boost the development of a sustainable real economy. Under traditional technical conditions, high energy density is caused due to the use of obsolete machinery with outdated technology. The more products that are produced, the more adverse effects energy development causes for the real economy.

Secondly, the spatial spillover effect of technological innovation on the real economy is not significant. To be more specific, technological advancement in one province does not necessarily lead to the development of the real economy in the neighboring province(s) due to a cluster effect in the high-tech sector. This is also because the market mechanisms for technology trading are not yet mature, which negatively impacts the flow of technologies. In addition, local governments are self-oriented when it comes to economic development and usually compete with each other to attract a high-technology consortium. This leads to weak supply chain linkages along the Belt. Consequently, the spillover effects of technological innovation on the real economy are not significant. Furthermore, spatial spillover effects of energy development on the sustainable real economy are significantly negative. Economic development in one province leads to the "siphon phenomenon" in the region, where resources, including energy consumption, will be concentrated in one place.

Thirdly, the impact of energy development on the development of the real economy is shaped by the threshold effect of the level of technological innovation. When the level of technological innovation is low, the impact of energy development on the sustainable real economy is not significant. When technological innovation achieves a certain level, technological innovation will be leveraged to optimize energy structures and improve energy efficiency. In this regard, the Pareto optimal effect of energy development on the real economy could be achieved.

Lastly, in the Belt region, the level of technological innovation has achieved the respective threshold. Under this scenario, energy development should have boosted the real economy. This boosting effect has not yet been observed. This brings up the issue of policy fragmentation across different dimensions of development. Going forward, the interaction of policies, where the aggregate impact is different from the sum of the individual impacts, may offer unique opportunities for achieving development strategies including carbon neutrality goals and "dual-circulation". In this regard, the Belt region should move towards synergies by agenda-setting and implementing improvements in the sustainable development of the real economy, as well as by making the region a pioneer in high-quality development and green growth.

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