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Dynamic Effects and Regional Differences of Industrialization and Urbanization on China's Energy Intensity under the Background of "Dual Carbon"

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Abstract: Based on China's provincial panel data during 2012–2019, this paper performs an empirical analysis of the dynamic effect and regional difference of industrialization and urbanization on the energy intensity in China by separating the energy intensity into three levels including low, middle and high and using the dynamic panel data with system GMM estimation. The results show that the energy intensity will increase by 0.4298% for every 1% increase in the industrialization level on the premise of keeping other variables unchanged. For every 1% increase in the urbanization level, the energy intensity will increase by 0.5674% on average. For every 1% increase in energy intensity in the previous period, the energy intensity in that year will increase by 0.7968% on average. Moreover, there are regional differences in the effects of industrialization and urbanization on the energy intensity in areas with different energy intensities. In addition, all of the factors including the development level of the regional economy, energy price, and technological innovation have different effects on the energy intensity in China. Meanwhile, there exist the rebound effects of the technological innovation in China, and the energy price has an induced effect on the technological innovation. Undoubtedly, industrialization and urbanization jointly promote the increase in energy intensity. At the same time, the level of economic development, energy prices and technological innovation are also reasons for the differences in the energy intensity among regions. Therefore, in order to effectively reduce energy intensity while carrying out technological innovation, promoting high-quality development and increasing income, it is necessary to improve the internal quality of industrialization and urbanization, and to promote new resource-saving and environmentally friendly methods of industrialization and urbanization.

Keywords: industrialization; urbanization; energy intensity; dynamic effect; regional differences

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1. Introduction

In 2021, the shadow of the COVID-19 pandemic has not faded, local military conflicts have flared up one after another, and the world has suddenly been plunged into an energy crisis. Energy prices continue to rise and the energy crisis is getting worse. With the increasingly prominent energy problems, how to improve energy efficiency, realize the transformation of the energy-consumption mode, and reduce energy intensity has become a major theoretical and practical problem to be urgently solved. President Xi Jinping's decision to be "carbon neutral by 2060" during the 75th Session of the United Nations General Assembly has prompted other countries to reflect and may serve as a model for them to learn from, a move that will have a positive impact on reducing global energy consumption. Since the beginning of the 21st century, China's level of industrialization has been continuously improved, with industrial added value reaching 31,307.11 billion yuan in 2020, which is 1.5 times that of 2012, indicating an average annual growth of 5.19% [1]. The development of industrialization is manifested in the development of high-energy-consumption industries; the six industries with high energy consumption (chemical raw material and chemical product manufacturing industry, non-metallic mineral product industry, ferrous metal smelting and rolling processing industry, non-ferrous metal smelting and rolling processing industry, petroleum processing coking and nuclear fuel processing industry, and the power and thermal production and supply industry) have especially developed rapidly. However, due to China's industrialization, especially since the task of heavy industrialization has not yet been achieved, the future economic structure will still be an industrial economic structure dominated by heavy industry. Therefore, the phenomenon of high energy intensity will continue to exist. At the same time, the level of urbanization accompanied by industrialization will continue to improve, which is bound to further enhance the energy intensity. In 2020, China's urban population reached 902.2 million, and the population urbanization rate rose to 63.89%, which is an increase of 10.79% over 2012 [1]. With the rapid development of industrialization and urbanization, residents' income and consumption will continue to increase, especially for industrial products such as electronic products, plastic products and metal products. Therefore, the improvement of industrialization and urbanization will certainly enhance the intensity of energy consumption. In this context, research on the dynamic effects and regional differences of industrialization and urbanization on energy intensity will undoubtedly have important theoretical and practical significance for solving the problems of the continuous reduction in energy and resources faced by China's sustainable economic development.

2. Literature Review

As a hot issue of academic and government attention, researchers at home and abroad have conducted a lot of research on the relationship between industrialization, urbanization and energy consumption, and have achieved fruitful results.

2.1. The Empirical Literature from Overseas

Foreign qualitative research on this issue mostly focuses on the internal mechanism of industrialization and urbanization with respect to energy consumption. Samouilidis and Mitropoulo [2] found that modern industrial activities can significantly increase energy consumption. Sathaye et al. [3], when inspecting the urbanization process in developing countries, pointed out that the development of urbanization can inevitably lead to changes in the energy-consumption structure, that is, coal will be gradually replaced by oil and the speed will be faster and faster. Owens, S. and Breheny, M [4] pointed out that with the population growth and industrial development of small cities, transportation will increase energy consumption, and the implementation of small-city-development policy is not conducive to saving energy consumption. Hiroyuki [5] performed an empirical analysis of the data of different countries and concluded that energy consumption and urbanization are positively correlated. Schneider and Enste [6] believe that the main channel for urbanization to affect energy consumption is production. With the concentration of economic-production activities in urban areas, economies of scale will be generated. Production activities will change from low-energy-intensive agriculture to high-energy-intensive industries. At the same time, energy will change from a rural, decentralized use of energy transfer to an urban, centralized use of modern energy. Wei B R, et al. [7] think that while urbanization promotes economic development, it also naturally promotes the increase in energy consumption. However, it is precisely because of the promotion of urbanization that technology, industrial structure and resources are reasonably allocated and adjusted, which leads to the reduction of energy consumption. The research by Pachauri and Jiang [8] shows that the per capita energy consumption in cities is lower than in rural areas due to the shift from low-efficiency solid-state combustion energy (such as biomass and raw coal) to clean and high-efficiency energy (such as natural gas, electricity, etc.).

The quantitative research on this issue in foreign countries ranges from shallow to deep and is gradually deepening, including cross-sectional data, time series data, and panel data. Schipper et al. [9] found that about 50% of energy consumption is caused by residents' consumption. Jones [10] selected cross-sectional data of 59 developing countries in 1980 for analysis, and found that the energy intensity increased by 0.35% for every 1% increase in the urbanization level. Parikh and Shukla [11], using data from developing and developed countries from 1965–1987, pointed out that the urbanization elasticity of energy consumption was approximately between 0.28–0.47. Holtedahl and Joutz [12] used data of Taiwan from 1955 to 1995, and found a positive correlation between urbanization and per capita energy consumption through a co-integration analysis. York R. [13] analyzed the determinants of energy consumption in EU countries from 1960 to 2005 and thinks that the urbanization elasticity of energy consumption was approximately between 0.29–0.56, and the income elasticity was between 0.52–0.69. Liddle, B. and Lung, S. [14], using the STIRPAT model and data from 17 developed countries in 1960–2005, think that urbanization was positively correlated with residents' energy consumption. Poumanyvong P and Kaneko S. [15], using data from 99 countries during 1975–2005, pointed out that the impact of urbanization on energy consumption showed different characteristics with different stages of economic development. Based on the data of 76 developing countries from 1980–2010, Sadorsky [16] found that the industrialization elasticity of energy intensity was between 0.05–0.06, and the impact of urbanization on energy intensity was not significant.

2.2. The Empirical Literature from Domestic

With the rapid advancement of urbanization and the rapid growth of energy consumption in China, domestic scholars pay more and more attention to the impact of industrialization and urbanization on energy consumption. He Xiaoping et al. [17] established a nonlinear model of panel data and, using the method of comparative analysis, studied the impact of urbanization on China's electricity demand and predicted that urbanization and electricity demand would show a high correlation. Kan Daxue and Luo Liangwen [18] conducted empirical studies on urbanization and energy intensity using panel data and spatial econometric methods. Based on EKC theory, Bai Jiyang [19] empirically analyzed the relationship among economic development, urbanization and energy consumption, and pointed out that China's economy has not yet reached the inflection point of the EKC inverted "U" curve. The improvement of economic development and the advancement of urbanization will stimulate the growth of energy consumption. In particular, the unreasonable industrial structure is the main factor leading to the excessive growth of energy consumption in China. Therefore, only by formulating reasonable energy strategies can we effectively solve the energy problems caused by economic development, urbanization and the unreasonable industrial structure. Hu Zongyi et al. [20] conducted a study based on cross-sectional data in 2007, and found that investment level, industrial structure and energy-consumption structure were the main factors that cause significant regional differences in energy efficiency. Wang Xiaoling et al. [21] found that the improvement of urbanization has a strong role in promoting the decline of energy intensity based on 1990–2009 time series data. Ma Heng [22] established a multiple linear regression model to estimate the impact of urbanization and industrialization on energy consumption in China. Zhang Rui and Ding Rijia [23] analyzed the impact of industrialization and urbanization on energy intensity based on provincial panel data in different periods. Li Biao et al. [24] constructed static and dynamic panel models to empirically analyze the relationship between urbanization, industrialization, informatization and energy intensity. Wang Keying and Zhang Hongwu [25] pointed out that the energy intensity and real GDP per capita changed in the opposite direction, and changed in the same direction as the level of industrialization.

In summary, the current research shows three characteristics. First, in terms of research objects, existing studies have focused on the regional differences in energy consumption and energy intensity, which often divides the mainland of China into the eastern, central and western regions according to the level of economic development. However, it is rare to divide the dynamic effects and regional differences according to the level of energy intensity. Second, in terms of research methods, the lag period of energy intensity is likely to have a significant indigenous impact on the current period. The parameter estimation of the generalized moment estimation of the first-order lag term of the dependent variable will be between the results of the fixed-effect and the mixed ordinary-least-squares method, and the estimation results are more reliable. Third, in terms of research conclusions, researchers believe that industrialization has led to the improvement of energy intensity, but there are still differences in terms of the impact of urbanization on energy intensity. The latest data are used to examine this difference. Based on the existing research results, this paper selects the provincial panel data of China from 2012 to 2019, and performs an empirical analysis of the dynamic effects and regional differences of industrialization and urbanization on China's energy intensity by using the system-generalized moment (SYS-GMM) analysis method of the dynamic panel data model, so as to comprehensively evaluate the dynamic effects and regional differences of industrialization and urbanization on China's energy consumption, and to provide some countermeasures and suggestions to reduce energy intensity based on the research conclusions.

3. Theoretical Analysis

3.1. Influence Mechanism of Industrialization on Energy Intensity

Industrialization is an insurmountable stage for any undeveloped country to reach prosperity. With the development of industrialization, the utilization efficiency of energy as one of the production factors also changes. At the beginning of industrialization, the leading industries of agriculture and handicraft gradually transition to light industry, and the energy elasticity coefficient is lower, meaning that the hindering effect of energy on economic development is not yet present. The energy intensity is still very low. When the economy enters the stage where heavy industry is the leading industry, the demand for resources for economic growth will rise rapidly, as will the dependence on energy. The hindrance of energy on economic growth begins to appear, and the energy intensity increases accordingly. At the same time, the harm of industrialization to the economy and the environment increases. As energy constraints become increasingly prominent, people begin to pay more attention to energy efficiency, and try to continuously improve energy efficiency through technology while eliminating high-energy-consuming industries, which causes energy intensity gradually decline.

According to the viewpoint of Bernardini and Galli [26], agriculture is the leading industry in the pre-industrial stage, and human basic needs are the driving force for economic growth; this period has the lowest energy intensity. In the industrialization stage, infrastructure construction leads to high energy consumption coupled with low technological levels, and energy intensity increases significantly. Subsequently, with the progress of technology and the emergence of lower-energy-consumption substitute materials, the energy intensity begins a downward trend. In the post-industrialization stage, with the economic structure changing from an industry-oriented industry to a service-oriented industry, the proportion of the manufacturing output value decreases, and the proportion of the service output value increases. Compared with the basic manufacturing economy, the correlation between energy intensity and the service-oriented economy is lower, and the energy intensity will gradually decrease.

The most obvious feature of industrialization is the continuous evolution of the three industries, and the productivity levels among the three industries are very different. Therefore, when the factors flow among different industries, it will inevitably cause changes in factor productivity. The impact of industrialization on energy efficiency can be analyzed in terms of two aspects. On the one hand, there exists enough energy as a support in the process of industrialization, and energy is indispensable as the production factor of the industrial sector. At present, China has now entered the period of the middle–late industrialization phase, which has consumed a lot of mineral and fossil resources, and energy consumption has increased year by year. On the other hand, within industry, the energy intensity of heavy industry is much higher than that of light industry. In addition, the economic growth in many regions of China depends on the development of heavy industry, which consumes a lot of energy resources. According to the "Structural Dividend

Hypothesis", there is a great difference in inter-sector productivity. When energy factors flow from the inefficient sector to the efficient sector, it will cause the overall improvement of energy efficiency in the whole society.

Therefore, energy intensity also changes in different stages of industrialization. Because of the unbalance of regional development in China, the degree of industrialization is accordingly different. In the eastern region, the development has been relatively early and the degree of industrialization is relatively high, while the economic development is relatively late and slow, and the degree of industrialization is also relatively low in the central and western regions. Therefore, it is necessary to examine the impact of industrialization on energy intensity in different regions.

3.2. Influence Mechanism of Urbanization on Energy Intensity

Urbanization mainly affects energy intensity through three aspects. (i) Urbanization affects energy intensity through industrial agglomeration. Aggregation is the most obvious economic characteristic of urbanization. Urbanization is the continuous allocation and integration of production factors in time and space. The industrial agglomeration effect of urbanization is mainly focused on the following aspects: First, industrial agglomeration benefits the generation and sharing of new technology. Industrial agglomeration in cities shortens the spatial and geographical distance among enterprises, which is not only conducive to promoting the exchange of information among enterprises and establishing long-term and stable cooperation relations, but also conducive to the exchange and sharing of technology innovators, improving the technological innovation ability of the industry, and thus improving resource efficiency. Second, industrial agglomeration is also conducive to enhancing the ability of enterprises to absorb new technologies. The income level of urban areas is higher than that of rural areas. It is not only beneficial for enterprises to hire high-tech talents with professional knowledge and rich experience, but also for enterprises to absorb and transform new technologies in the process of operation, so as to improve energy efficiency. Third, urbanization promotes enterprises to improve their innovation ability. Enterprises are mainly concentrated in cities. In order to stand out from the market competition, enterprises must enhance their ability to develop new products and open up new markets to reduce their production costs, improve production efficiency and improve energy efficiency. (ii) Urbanization affects energy intensity through the economic growth effect. Urbanization is an important feature of economic growth. Urbanization promotes economic growth and thus affects energy intensity. For example, urbanization increases the demand for infrastructure. With the development of the city, infrastructure becomes more perfect, which will increase the demand for energy and raw materials; urbanization will affect transportation by increasing the number of motor vehicles entering and leaving urban areas, and this change will increase the demand for energy; urbanization can affect energy demand by influencing individual consumption. With the advancement of urbanization, urban residents become richer, and their consumption patterns shift to higher-energy products, such as computers, cars, refrigerators and air conditioning, etc. With the rapid increase in urbanization, economies of scale, technological progress and a more effective allocation of resources contribute to the reduction in energy intensity. Industrialization and urbanization are regarded as two main manifestations of modern economic growth. The growth of the secondary industry reflects the increase in the amount of urbanization, that is, the speed and quantity of urban scale expansion, while the tertiary industry focuses on the quality improvement of urbanization, which continuously improves the software and hardware infrastructure of the city and improves the living standards of residents. Throughout the development of urbanization in China, industrialization has played a very important role. However, the tertiary industry is playing an increasingly important role.

4. Regional Distribution of Energy Intensity

Since the reform and opening up, China's economy has been growing at a high speed, but along with the economic growth, the energy consumption has also been increasing day by day. The continuous growth of energy consumption has caused great pressure on the ecological environment, which has seriously affected people's living environment. Many ecological and environmental problems caused by energy consumption, such as the greenhouse effect, have increasingly restricted economic development. According to the data of ***World Energy Statistics Yearbook 2020*** released by BP, since 2009, China's total energy consumption has surpassed that of the United States, becoming the largest energy consumer in the world. The results are shown in Table 1.

Table 1. Total energy consumption of major countries Unit: 100 million tons of standard coal.

Year	Globe	China	America	Russia	India	Other Countries
2009	164.7	33.3	30.7	9.2	7.3	84.3
2010	172.7	35.6	31.7	9.6	7.7	88.1
2011	176.9	38.4	31.4	9.9	8.1	89.0
2012	179.1	39.9	30.6	9.9	8.6	90.1
2013	182.5	41.4	31.4	9.8	8.9	91.0
2014	184.0	42.3	31.7	9.8	9.5	90.6
2015	185.3	42.8	31.4	9.6	9.8	91.7
2016	187.9	43.3	31.4	9.8	10.3	93.1
2017	191.2	44.6	31.5	9.9	10.7	94.5
2018	196.6	46.3	32.6	10.2	11.4	96.1
2019	199.2	48.3	32.3	10.2	11.6	96.8

Source: Beijing Hengruixing Information Consulting Co., Ltd.: ***BP World Energy Statistics Yearbook 2020***, Beijing Hengruixing Information Consulting Co., Ltd., 2010–2020.

During 2009–2019, China's total energy consumption increased from 3.33 billion tons of standard coal to 4.83 billion tons of standard coal, with an average annual growth rate of 3.79%, which was almost twice that of global energy consumption. As a developed country, in the United States, the total energy consumption has grown from 3.07 billion tons of standard coal to 3.23 billion tons of standard coal, with an average annual growth rate of 0.51%, and the total energy consumption is basically stable at about 3.2 billion tons of standard coal. Russia's total energy consumption has increased from 920 million tons of standard coal to 1.02 billion tons of standard coal, with a growth rate of 1.04%, which is lower than the global average growth level. As a developing country, India's total energy consumption has increased from 730 million tons of standard coal to 1.16 billion tons of standard coal, with an average annual growth rate of 4.74%, which is 2.5 times that of the global level. The growth rate of energy consumption is obviously higher than that of China. According to the proportion of total energy consumption in each country, the top countries are China, the United States, Russia and India. In recent years, China's share of the global energy consumption has also been increasing, from 20.22% in 2009 to 24.25% in 2019. In contrast, the share of the United States decreased from 18.64% to 16.21%, that of Russia decreased from 5.59% to 5.12%, and that of India increased from 4.43% to 5.82%. The comprehensive share of energy consumption in other countries basically remained around 50% and showed a downward trend.

Table 2 shows that from 2009 to 2019, the energy intensity of China, the United States, Russia and India all showed a downward trend. In 2015, the global energy intensity rebounded slightly, and then it returned to a downward trend. The energy intensity of other countries fluctuates slightly, but tends to decline in general. Currently, China's energy intensity is still at a high level, which is higher than the world average level, second only to Russia and India. However, since 2009, China's energy intensity has dropped at the fastest rate, reaching 6.76%, which is much higher than the 3.5%, 2.19% and 3.74% of the United States, Russia and India, and also higher than the global 2.22%.

On 24 October 2012, China's State Department Press Office issued a white paper on China's Energy Policy, which stated that maintaining the long-term stable and sustainable use of energy resources is an important strategic task of the Chinese government. China's energy must take the development path of high scientific and technological content, low resource consumption, less environmental pollution, good economic benefits, safety, and security, so as to achieve conservation, as well as clean and safe development. Undoubtedly, the release of the white paper will have a significant impact on China's energy consumption. Due to the extremely unbalanced economic development in various regions of China, the impact of industrialization and urbanization development in various regions on energy intensity also shows great differences. Therefore, in order to reflect the difference in regional energy intensity, this paper selects the sample data of 30 provinces in China from 2012 to 2019 (Taking into account the incomplete data of Tibet, this paper excludes it in the study, so it only includes 30 provinces, autonomous regions and municipalities in mainland China). According to the ascending order of the average energy intensity in each region and the descending order of the average GDP, the ranking results are shown in Table 3.

Table 2. Energy intensity of major countries Unit: 10,000 tons of standard coal/100 million USD.

Year	Globe	China	America	Russia	India	Other Countries
2009	2.8427	6.7835	2.1534	7.4845	5.9061	2.3219
2010	2.7452	6.0562	2.1627	6.5525	5.0065	2.2377
2011	2.5395	5.2616	2.0803	5.3502	4.8326	2.0347
2012	2.4977	4.8499	1.9509	4.8961	4.7128	2.0501
2013	2.4431	4.4804	1.8690	4.6738	4.7421	2.0364
2014	2.3629	4.0830	1.8199	5.2671	4.5963	1.9626
2015	2.5234	3.9387	1.7496	7.2398	4.7263	2.2246
2016	2.4841	3.8664	1.6910	7.6372	4.5505	2.1996
2017	2.3697	3.6445	1.6245	6.2758	4.1193	2.1056
2018	2.2916	3.4024	1.5907	6.1535	4.1815	2.0315
2019	2.2700	3.3675	1.5074	6.0004	4.0346	2.0419

Source: (i) Beijing Hengruixing Information Consulting Co., Ltd.: ***BP World Energy Statistics Yearbook 2020***, Beijing Hengruixing Information Consulting Co., Ltd., 2010–2020; (ii) National Bureau of Statistics of China: China Statistical Yearbook, China Statistics Press, 2010–2020.

Energy intensity is one of the common indicators used to evaluate the comprehensive utilization efficiency of energy in a country (region), which reflects the cost of environmental resources that is paid in the process of the economic development of a country (region). With the increasingly prominent energy shortage, how to realize the transformation from energy consumption and extensive economic development to resource-saving and environmentally friendly development has become a major theoretical and practical problem to be solved. For an economy, energy intensity is defined as the energy consumption per unit of GDP in a certain period of time, which is an indicator to measure energy efficiency. The results in Table 3 show that, in general, the provinces with a relatively low average energy intensity are often provinces with a relatively high average GDP, which is highly likely to be due to the scale effect of energy consumption in the process of economic development, i.e., the higher the level of economic development, the more conditionally the regions pay attention to energy consumption. Among the ten provinces with the lowest average energy intensity, there are five provinces with the highest average total GDP; among the ten provinces with the highest average energy intensity, seven provinces have the lowest average total GDP. In this paper, according to the descending order of the average total energy intensity, the top ten provinces are classified as low-energy-intensity areas, the middle ten provinces are classified as medium-energy-intensity regions, and the last ten provinces are classified as high-energy-intensity regions (Generally, the mainland of China is divided into the eastern, central and western regions, and the division methods of the three regions are as follows: the eastern region includes the 11 provinces of Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan; the central region includes the 8 provinces of Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan; The western region includes 12 provinces of Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. According to the average energy intensity, this paper divides 30 provinces, municipalities and autonomous regions in Chinese mainland except Tibet into three regions).

Table 3. Average ranking of provincial energy intensity and GDP in China.

	Ranking	Region	Average Energy Intensity (10,000 TCE/100 Million Yuan)	Region	Average of Total GDP (100 Million Yuan)
Top 10	1	Beijing	0.2866	Guangdong	79,459.26
	2	Fujian	0.3447	Jiangsu	75,562.66
	3	Guangdong	0.4028	Shandong	64,483.54
	4	Jiangsu	0.4192	Zhejiang	46,631.24
	5	Shanghai	0.4270	Henan	40,133.84
	6	Zhejiang	0.4401	Sichuan	33,257.92
	7	Jiangxi	0.4793	Hubei	32,163.75
	8	Hainan	0.5001	Hebei	31,430.85
	9	Tianjin	0.5021	Hunan	30,543.46
	10	Hunan	0.5223	Fujian	28,849.70
Middle10	11	Chongqing	0.5264	Shanghai	27,542.23
	12	Anhui	0.5276	Liaoning	25,654.52
	13	Hubei	0.5365	Beijing	25,175.12
	14	Jilin	0.5671	Anhui	24,730.27
	15	Henan	0.5837	Shaanxi	19,737.60
	16	Guangxi	0.5877	Jiangxi	18,130.63
	17	Shandong	0.6140	Guangxi	17,298.95
	18	Sichuan	0.6151	Inner Mongolia	17,140.61
	19	Shaanxi	0.6157	Chongqing	16,913.38
	20	Yunnan	0.7529	Tianjin	16,118.69
Last 10	21	Heilongjiang	0.7828	Yunnan	15,105.65
	22	Liaoning	0.8671	Heilongjiang	14,941.58
	23	Guizhou	0.9214	Shanxi	14,091.21
	24	Hebei	0.9885	Jilin	13,671.84
	25	Gansu	1.0574	Guizhou	11,450.17
	26	Inner Mongolia	1.1843	Xinjiang	10,109.41
	27	Shanxi	1.4181	Gansu	7154.08
	28	Xinjiang	1.5722	Hainan	3986.66
	29	Qinghai	1.6524	Ningxia	3081.07
	30	Ningxia	1.8832	Qinghai	2470.56

Notes: (i) National Bureau of Statistics of the People's Republic of China: ***China Statistical Yearbook***, China Statistical Press, 2013–2020; (ii)Department of Energy Statistics, National Bureau of Statistics: ***China Energy Statistical Yearbook***, China Statistical Press, 2013–2020.

5. Model Construction and Index Selection

5.1. Model Construction

According to the previous theoretical analysis, combined with the research results of Jones [10], the standard time series model to study the impact of industrialization and urbanization on energy-consumption intensity can be set as follows:

$$LnEI_t = \alpha_0 + \alpha_1 LnIND_t + \alpha_2 LnURB_t + \alpha_3 LnPGDP_t + \alpha_4 LnEP_t + \alpha_5 LnPAT_t + \varepsilon_t \quad (1)$$

The coefficients in Model (1) reflect the elastic relationship between explanatory variables and explained variables. Model (1) can be extended to the static panel data model to obtain Model (2):

$$LnEI_{it} = \alpha_i + \alpha_1 LnIND_{it} + \alpha_2 LnURB_{it} + \alpha_3 LnPGDP_{it} + \alpha_4 LnEP_{it} + \alpha_5 LnPAT_{it} + \mu_t + \nu_{it} \quad (2)$$

Model (1) is a classical time series model. If Model (1) is used to study the impact of industrialization and urbanization on energy consumption, then it cannot measure the dynamic impact and regional differences caused by the unbalanced regional distribution of industrialization and urbanization. For Model (2), although the static panel data model can measure the regional differences in the impact of industrialization and urbanization on energy intensity, neither it nor Model (1) can examine the dynamic effect of industrialization and urbanization on energy intensity, that is, the energy intensity in the previous period may have an impact on the energy intensity in the current period and subsequent periods. Both Model (1) and Model (2) assume that the industrialization and urbanization in previous periods have the same impact on the current energy consumption, and this assumption is not consistent with economic theory or the actual situation in China. Energy intensity change is a continuous dynamic process, which is not only affected by current factors, but also by past factors [27]. Drawing on Perry Sadorsky [16] for reference to study the impact of energy intensity on developing countries, the dynamic model method is adopted and the one-period lagged energy intensity term is added. In addition, in order to make full use of the sample information as much as possible, to reduce the collinearity between variables, and to make the parameter estimation more effective, panel data can be selected as the research object. To accurately examine the dynamic effects of industrialization and urbanization on energy intensity in different regions of China in this paper, Model (2) is extended to the dynamic panel data Model (3) (The dynamic panel data model can contain high-order lag terms. However, through the test, it was found that only the first-order lag was obvious, so the dynamic panel data model constructed in this paper does not list high-order lag terms).

$$LnEI_{it} = \beta_i + \beta_1 LnEI_{it-1} + \beta_2 LnPGDP_{it} + \beta_3 LnIND_{it} + \beta_4 LnURB_{it} + \beta_5 LnEP_{it} + \beta_6 LnPAT_{it} + \mu_t + v_{it} \quad (3)$$

Since the impact of technological innovation on energy intensity is not the same at different levels, that is, there is a "rebound effect", the square of the natural logarithm of the variable reflecting the level of technological innovation and the natural logarithm of the variable reflecting the level of technological innovation are added to Model (3) to represent the long-term impact of technological innovation on energy intensity, so as to verify whether there is a "rebound effect" of technological innovation. Therefore, a dynamic panel data Model (4) is built based on the Model (3).

$$LnEI_{it} = \beta_i + \beta_1 LnEI_{it-1} + \beta_2 LnIND_{it} + \beta_3 LnURB_{it} + \beta_4 LnPGDP_{it} + \beta_5 LnEP_{it} + \beta_6 LnPAT_{it} + \beta_7 LnPAT_{it}{}^2 + \mu_t + v_{it} \quad (4)$$

According to the factor price and factor demand theory of Western economics, the change in factor price will inevitably affect the demand and utilization of the factors. In 1932, British economist John Richard Hicks [28] first proposed the concept of "induced invention", which means "changes in factor prices will induce technological innovation used to directly save other elements of rising factor prices". Because the change in energy price will induce the role of energy technology invention (innovation), the dynamic effect on energy intensity is formed indirectly. Therefore, this paper adds a product term reflecting the energy price and technological innovation level to Model (4).

$$LnEI_{it} = \beta_i + \beta_1 LnEI_{it-1} + \beta_2 LnIND_{it} + \beta_3 LnURB_{it} + \beta_4 LnPGDP_{it} + \beta_5 LnEP_{it} + \beta_6 LnPAT_{it} + \beta_7 LnPAT_{it}{}^2 + \beta_8 LnEP{*}LnPAT + \mu_t + v_{it} \quad (5)$$

*LnEP*LnPAT* is the cross term of the energy price and the technological innovation level. If its coefficient is positive, then it indicates that the effect of the decrease in energy intensity caused by the rise in energy price is relatively weak, which means that the change in China's energy price is to achieve the dynamic effect of energy intensity by inducing technological innovation.

In Models (3)–(5), $i = 1, 2, 3, \ldots, N$ represents different individuals, $t = 1, 2, 3, \ldots,$ T represents the sample year, β_i and μ_t represent the regional and time effects used to control the unobservable, respectively, and v_{it} is a random disturbance term.

5.2. Description of Variables and Data Sources

(I). Energy intensity (EI). This index is one of the commonly used indexes to compare the comprehensive utilization efficiency of energy in different regions, which reflects the economic benefits of energy use. In this paper, the energy consumption per unit of gross domestic product (GDP) is selected, that is, the energy consumption per unit of GDP reflects the energy intensity. Among them, GDP is the actual GDP calculated based on the price in 2000.

(II). Industrialization (IND). Compared with traditional agricultural production or manufacturing, the increase in industrial activities will lead to more energy use and increase energy intensity. The level of industrialization is usually measured by the proportion of the added value of the secondary industry in the total output value or the proportion of industrial employees in the total employment. In this paper, the proportion of industrial added value to the GDP is used to measure the industrialization level.

(III). Urbanization (URB). As for the measurement of the urbanization level, different countries or regions adopt different indicators. On the one hand, in the process of urbanization, economic activities related to consumption and production are highly concentrated in cities, which is likely to increase the use of energy; on the other hand, in the process of urbanization, production activities are highly concentrated and scale economies are likely to exist, which is certain to improve the efficiency of energy use. The effects of the two aspects lead to the uncertainty of the impact of urbanization on energy intensity. This paper measures the urbanization level by the proportion of urban population to the total population in this area.

(IV). Economic development level (PGDP). There are a few differences in the measurement of the economic development level, which is generally measured using GDP or per capita GDP. With the improvement of economic development, energy intensity will show regular changes. Bernardini and Gali found that with the increase in income, energy intensity will decrease. Since per capita GDP excludes the impact of population changes, it can reflect the real situation of economic growth. Therefore, this paper uses per capita real GDP to measure the level of economic development, which is still based on 2000.

(V). Energy price (EP). Energy prices are generally measured by industrial producer fuel and power purchase price indices, which may be more reasonable. However, it is difficult to obtain the purchasing price index of fuel and power by region. This paper selects the relatively reasonable retail price index of fuel commodities to measure and uses 2001 as the base period for reduction.

(VI). Technological progress (PAT). Technological change is considered to be the most effective way to improve energy efficiency. The patent application authorization has traceability and the data acquisition is more convenient, which basically reflects the speed of technological progress. This paper selects the number of granted patents per ten thousand as the indicator of technological progress.

The data selected in this paper are annual data, and the research objects are 30 provinces, autonomous regions and municipalities in mainland China, except Hong Kong, Macau, Taiwan Province and Tibet. The provincial total energy consumption, regional GDP, number of patent applications granted, total population, fuel price index (2000 as the base period) and other data in this paper are from ***China Statistical Yearbook***, ***China Energy Statistical Yearbook*** and the statistical yearbooks of all provinces, autonomous regions and municipalities directly under the Central Government, etc., and some supplementary data are from ***the Compilation of Statistical Data of 60 Years of New China*** and ***CEIC China Economic Database***. If the above methods are still unable to obtain data, the moving-average method or interpolation method is used to supplement or estimate by referring to other estimation methods. The gross regional product is calculated in terms of constant prices in 2000. In order to maintain the good nature of parameter estimation, all of the variables are taken as natural logarithms. Table 4 reports the statistical description of related variables.

Table 4. Descriptive statistics of related variables.

Variable	Symbol	Unit	N	Mean	Std. Deviation	Minimum	Maximum
energy intensity	EI	MTCE/ 100 million yuan	240	0.76	0.4506	0.057	2.09
industrialization	IND	%	240	33.46	11.41	1.529	96.36
urbanization	URB	%	240	58.20	11.90	36.41	89.60
economic development level	PGDP	ten thousand yuan	240	5.50	2.561	1.89	16.18
energy price	EP	—	240	100.43	6.36	83.50	113.00
technological progress	PAT	granted patents/ ten thousand people	240	10.62	12.14	0.24	60.14

Notes: (i) National Bureau of Statistics of the People's Republic of China: ***China Statistical Yearbook***, China Statistical Press, 2013–2020; (ii) Department of Energy Statistics, National Bureau of Statistics: ***China Energy Statistical Yearbook***, China Statistical Press, 2013–2020.

6. Model Estimation and Result Interpretation

The 18th National Congress of the Communist Party of China held in October 2012 opened a new journey for the construction of China's socialist market economy. Since 2012, it has also been a period of the rapid development of industrialization and urbanization in China. Considering the availability of data, this paper selects the provincial sample data of 30 provinces, municipalities and autonomous regions (excluding Hong Kong, Macao, Taiwan and Tibet) in the mainland of China from 2012 to 2019 and uses the econometric analysis software stata17 to estimate and test Models (4) and (5).

In the actual calculation, it is found that the t-statistics of the second-order lag become very insignificant when the lag period is 2, so the final model only selects the first-order lag. In the dynamic panel data Model (5), since the lag term of the dependent variable is used as the independent variable, the independent variable is related to the stochastic disturbance, that is, the model has endogenous problems. If the traditional fixed effect or random effect is used to estimate the dynamic panel data model, then it will inevitably lead to biased and inconsistent estimators. Therefore, the estimation results and economic implications obtained on this basis must be incorrect. Generally, when the fixed effect is used to estimate the model, the estimation results will shift downward because of the negative correlation between the lag term and the error term of the explained variable; when the mixed OLS is used to estimate the model, due to the positive correlation between the lag term of the dependent variable and the random disturbance, the estimation results will have an upward trend. In order to solve the above measurement problems, Anderson and Hisao [29] proposed the first-order differential IV estimator; Arellano and Bond [30] proposed the first-order difference-generalized moment (DIF-GMM) estimator; Arellano and Bover [31], as well as Blundell and Bond [32], proposed the system-generalized moment (SYS-GMM) estimator. At present, the first-order difference-generalized moment (DIF-GMM) estimator and the system-generalized moment (SYS-GMM) estimator are commonly used in academia. The main difference between the two estimators is that the difference-generalized moment (DIF-GMM) estimator uses the lag term of the horizontal value as the instrumental variable, while the system-generalized moment (SYS-GMM) estimator further uses the lag term of the difference variable as the instrumental variable, which is equivalent to increasing the number of instrumental variables and using both the horizontal equation and the difference equation in the estimation process; most importantly, the instrumental variable of the DIF-GMM estimator is usually a weak instrumental variable. Therefore, this paper uses the SYS-GMM estimation method to estimate Models (4) and (5), and the results are shown in Table 5.

Table 5. SYS-GMM estimation results of Models (4) and (5).

Variables	Model (4)	Model (5)
LnEI(-1)	0.7629 *** (0.1799)	0.7968 *** (0.2108)
LnIND	0.4103 *** (0.0761)	0.4298 *** (0.0699)
LnURB	0.5112 *** (0.0981)	0.5674 *** (0.1374)
LnPGDP	−0.4866 *** (0.1164)	−0.5721 *** (0.0947)
LnEP	−0.3332 ** (0.1512)	0.4032 ** (0.1911)
LnPAT	−0.1131 *** (0.0148)	−0.1406 *** (0.0216)
Ln(PAT^2)	0.1823 *** (0.0612)	0.2452 *** (0.0666)
LnEP*LnPAT	—	−0.1064 *** (0.0253)
Constant	0.5341 *** (0.1162)	0.2497 *** (0.0508)
Arellano–Bond test for AR(1)	0.0027	0.0031
Arellano–Bond test for AR(2)	0.2984	0.2797
Sargan test (*p*)	1.0000	1.0000
Sample number	240	240

Notes: (i) ***, ** indicate that they have passed the significance test at the level of 1% and 5% respectively; (ii) the values in brackets below the coefficient are standard errors; (iii) Arellano–Bond test for AR(1) and AR(2) is used to test whether the error term of the first-order difference has a serial correlation; (iv) the Sargan test (*p*) is used to determine whether there is over-identification of instrumental variables (the original assumption is that all instrumental variables are valid).

All of the SYS-GMM coefficients of the dynamic panel data Models (4) and (5) are statistically significant. The Arellano–Bond sequence correlation test results show that the residual sequences of the models have first-order autocorrelation, but there is no second-order autocorrelation. Moreover, both of the *p*-values of the Sargan test are 1.0000, indicating that the new endogenous variables are indeed effective. Based on the comprehensive test results, the GMM estimates of dynamic panel data Models (4) and (5) are unbiased and consistent. The results in Table 5 show that the coefficients of LnIND and LnURB in Models (4) and (5) are statistically significantly positive, which indicates that industrialization and urbanization lead to a substantial increase in energy intensity. After the cross term of the energy price and the technological innovation level is added to Model (5), except for the variable of energy price, the symbols, coefficients and significance levels of the other variables do not show significant changes, but a change to the plus and minus sign before the variable of energy price has taken place. When the cross term of the energy price and the technological innovation level is not added, its coefficient sign is negative. However, after the cross term of the two is added, its coefficient symbol is positive. The SYS-GMM estimation results based on Model (5) are interpreted one by one.

6.1. The Lag Effect of Energy Intensity

The coefficient β_1 of LnEI(-1) is 0.7968, which measures the dynamic effect on energy intensity of the energy intensity in the previous year. The energy intensity of the previous year has a positive impact on the energy intensity of the current year, that is, under the premise of keeping other variables unchanged, if the energy intensity of the previous year increases by 1%, then the energy intensity of that year will increase by 0.7968% on average.

6.2. The Effect of Industrialization on Energy Intensity

The coefficient β_2 of LnIND is 0.4298, which measures the impact of industrialization on the energy intensity of the year. With the increase in the proportion of industrial added value, the energy intensity will also rise, which may be related to the fact that the industrial sector usually consists of relatively high-energy-consuming sectors. From the results of the model estimation, the energy intensity will increase by an average of 0.4298% when the proportion of industrial added value in GDP increases by 1%, and the proportion of industrial added value also has a significant impact on the energy intensity. It is one of the very important factors affecting the energy intensity among regions, which provides evidence to explain the difference in energy intensity among regions.

6.3. The Effect of Urbanization on Energy Intensity

The coefficient β_3 of LnURB is 0.5674, which measures the impact of the urbanization level on the energy intensity of the year. β_3 is positive, which means that the improvement of the urbanization level will lead to an increase in energy intensity. If the urbanization level increases by 1%, then the energy intensity will rise by an average of 0.5674%. In general, the energy intensity produced by the highly concentrated urban population is much higher than that produced by the scarce rural population. Improving the level of urbanization will undoubtedly lead to an increase in energy intensity, especially an increase in living energy intensity.

6.4. The Effect of Economic Development Level on Energy Intensity

The coefficient β_4 of LnPGDP is -0.5721, which measures the impact of the economic development level of the year on the energy intensity of the year. The negative β_2 indicates that the level of economic development can largely reduce the intensity of energy consumption to a great extent. Under the impetus of high-quality economic development, with the gradual improvement of energy-consumption and utilization efficiency, the energy consumption per unit of GDP gradually decreases, which leads to a downward trend in energy intensity.

6.5. The Effect of Energy Price on Energy Intensity

The coefficient β_5 of LnEP is 0.4032. Model (4) separately examines the estimation results of energy price on energy intensity. The more the energy price increases, the more obvious its effect on reducing the energy intensity. However, after the introduction of the cross term LnEP*LnPAT between the energy price and the technological innovation level in Model (5), that is, when examining the indirect impact of energy price on energy intensity through the induction of technological innovation, the effect of the energy price rise on the reduction in energy intensity is relatively smaller, and the sign of β_4 is also changed from negative to positive, indicating that China's energy price indeed reduces the intensity of energy consumption by inducing technological innovation.

6.6. The Effect of Technological Innovation on Energy Intensity

The coefficient β_6 of LnPAT is negative, while the coefficient β_7 of LnPAT^2 is positive, indicating that there is a "U" type relationship between the level of technological innovation and energy intensity, that is, before the level of technological innovation is at the lowest point of the "U" type curve, with the improvement of the level of technological innovation, the intensity of energy consumption will become lower and lower; however, when the level of technological innovation exceeds the lowest point of the "U" curve, the improvement of technological innovation will lead to the gradual increase in energy intensity, which is the so-called "dilemmas of technological innovation" or "rebound effect of technological progress". The most likely reason for this phenomenon is that technological progress brought about by technological innovation improves the efficiency of energy use and increases people's opportunities for energy consumption, which leads to an increase in energy intensity. At present, China has not yet reached the stage of the "technological innovation paradox" experienced by developed countries, whether in areas with low energy intensity or areas with high energy intensity. Therefore, China should achieve the goal of reducing energy intensity by improving the level of technological progress. At the same time, for the product term of LnENP*LnPAT, on the one hand, technological innovation should be used to reduce the cycle of energy intensity in the short term; on the other hand, it is necessary to appropriately increase energy prices. These two conditions must be met simultaneously in order to achieve the goal of reducing energy intensity by enhancing technical factors.

7. Regional Differences in the Impact of Urbanization and Industrialization on Energy Intensity

In order to further study the differences in the effects of industrialization and urbanization on China's energy intensity among different regions, this paper is arranged according to the level of energy intensity in Table 3, namely, regions with low energy intensity (10 provinces), regions with high energy intensity (10 provinces) and regions with medium energy consumption (10 provinces) to estimate and test (The three regions divided in this paper are not based on geographical location or economic development level, but on average energy intensity. Among them, low-energy-intensity areas include Beijing, Guangdong, Jiangsu, Zhejiang, Fujian, Shanghai, Hainan, Jiangxi, Tianjin, Chongqing; medium-energy-intensity areas include Anhui, Guangxi, Hunan, Shandong, Shaanxi, Henan, Heilongjiang, Hubei, Sichuan, Jilin; high-energy-intensity areas include Liaoning, Yunnan, Hebei, Xinjiang, Gansu, Shanxi, Inner Mongolia, Qinghai, Guizhou and Ningxia). The estimated results are shown in Table 6.

Table 6. Model (5) regional SYS-GMM estimation results.

	Low-Energy-Intensity Areas	Medium-Energy-Intensity Areas	High-Energy-Intensity Areas
LnEI(-1)	0.7641 ***	0.6332 ***	0.8013 ***
	(0.0629)	(0.1020)	(0.0804)
LnIND	0.2137 **	0.2366 **	0.4233 ***
	(0.1032)	(0.1075)	(0.0996)
LnURB	-0.0911	0.4997 **	0.5887 **
	(0.2278)	(0.2746)	(0.3019)
LnPGDP	−0.5988 ***	−0.5887 ***	0.2694 ***
	(0.1386)	(0.1617)	(0.0842)
LnEP	1.2031 ***	0.4911 ***	0.4497 ***
	(0.2885)	(0.0967)	(0.0916)
LnPAT	−0.1179 ***	−0.1132 ***	−0.3547 ***
	(0.0400)	(0.0392)	(0.0597)
Ln(PAT^2)	0.2744 ***	0.0884 **	0.0113
	(0.0863)	(0.0429)	(0.0332)
LnEP*LnPAT	−0.2037 ***	−0.0299 **	−0.0957
	(0.0441)	(0.0157)	(0.1100)
Constant	0.5137 ***	0.8931 ***	0.6308 ***
	(0.1435)	(0.1933)	(0.1516)
Arellano–Bond test for AR(1)	0.0037	0.0045	0.0023
Arellano–Bond test for AR(2)	0.5298	0.7426	0.7911
Sargan test (*p*)	1.0000	1.0000	1.0000
Sample number	80	80	80

Notes: (i) ***, ** indicate that they have passed the significance test at the level of 1% and 5% respectively; (ii) the values in brackets below the coefficient are standard errors; (iii) in order to facilitate comparison, some insignificant variables are also listed in Table 6.

The results in Table 6 show that among almost all of the explanatory variables, including the previous energy intensity, economic development level, industrialization level, urbanization level, energy price and technological innovation, come to a conclusion that is basically consistent with the estimation results of the whole region. In other words, the energy intensity increases with the improvement of the previous energy intensity, industrialization level and urbanization level. The improvement of the economic development level, the continuous rise in energy prices and the continuous innovation of the technological level are conducive to reducing the energy intensity. Although the energy intensity in different regions is affected by many common factors, the effects of the same factors are not the same.

7.1. The Lag Effect of Energy Intensity

The coefficient of LnEI(−1) is positive in areas with low energy intensity, medium energy intensity and high energy intensity, which shows that regardless of the level of energy intensity, the energy intensity of the previous period has a positive impact on the current energy intensity. In addition, the effect on regions with medium energy intensity is the smallest, while the effect on regions with high energy intensity is the largest. Although on the whole, the improvement of the economic development level can reduce China's energy intensity, the effect is not the same for different regions. For regions with low and medium energy intensity, the improvement of the economic development level can reduce the energy intensity, while for regions with high energy intensity, the energy intensity will increase with the improvement of the economic development level.

7.2. The Effect of Industrialization on Energy Intensity

The coefficients of LnIND in low energy intensity, medium energy intensity and high energy intensity are 0.2137, 0.2366 and 0.4233, respectively, and the impact is relatively significant. With the improvement of the industrialization level, the energy intensity gradually increases and the response of high-energy-intensity areas is more obvious among the three regions divided according to energy intensity. Especially with the development of the economy, energy consumption generally shows a slow upward trend in the initial and medium-term stages of industrialization. When economic development enters the post-industrialization stage, the energy intensity begins to decline due to the significant change in the mode of economic growth.

7.3. The Effect of Urbanization on Energy Intensity

The coefficient of LnURB is significantly positive in regions with medium and high energy intensity, while it is negative but not significant in regions with low energy intensity. The results of the regional analysis show: first, the improvement of the urbanization level is completely consistent with the estimated trend of the whole country, that is, the improvement of the urbanization level is one of the important factors leading to the increase in energy intensity; second, the urbanization process is a process in which people's production and lifestyle change. Lifestyle directly affects the demand for energy consumer goods, which affects the intensity of energy consumption. The mode of production affects the energy intensity through the demand of energy elements in the production process, and the change in lifestyle will directly affect the demand of energy commodities, thus indirectly affecting the demand of energy elements. Third, in the process of urbanization in regions with medium and high energy intensity, the growth of various forms of productive energy consumption, the increase in urban living energy consumption and the phenomenon of excessive energy consumption and energy waste in the process of urbanization will all lead to the increase in energy intensity.

7.4. The Effect of Energy Price on Energy Intensity

The coefficients of LnEP are 1.2031, 0.4911 and 0.4497 in regions with low, medium and high energy intensity, respectively, and they are all statistically significant at the level of 1%, which is most likely due to the direct impact of the inter-regional energy price fluctuations on the energy intensity caused by the substitution effect. The cross term LnEP*LnPAT reflects the indirect impact of the inter-regional energy price changes on the energy intensity. In low-, medium- and high-energy-intensity regions, the coefficients of LnEP*LnPAT are in the sequence of −0.2037, −0.0299 and −0.0957, which are consistent with the impact of the energy price on the energy intensity in China as a whole. However, it is worth noting that the coefficient of LnEP*LnPAT is very significant in low- and medium-energy-intensity areas, but not significant in high-energy-intensity areas, which undoubtedly shows that the change in China's energy price has an inducing effect on technological innovation, and it plays a more obvious role in low- and medium-energy-intensity areas. Generally speaking, due to the relatively backward level of economic development in the regions with high energy intensity, the effect of induced technological innovation on the energy intensity is still not obvious. Therefore, it is necessary to induce technological innovation in low- and medium-energy-intensity areas to reduce the energy intensity of the region.

7.5. The Effect of Technological Innovation Energy Intensity

The coefficients of LnPAT are all negative, and the impact on the energy intensity is very significant; the coefficients of Ln (PAT^2) are all positive, and the coefficient is relatively significant in regions with low and medium energy intensity but not obvious in regions with high energy intensity. On the one hand, the result shows that the rebound effect of technological innovation exists in China by region. Technological innovation can reduce the energy intensity within a certain range, but after exceeding a certain critical value, the energy intensity will increase with the increase in technological innovation. Obviously, the impact of technological innovation on the energy intensity has a feature of a "U", that is, the so-called "rebound effect of technological progress" or "paradox of technological innovation"; on the other hand, especially in low-energy-consumption areas, the resilience effect of technological innovation is relatively large. Therefore, increasing the level of technological innovation may lead to a decline in energy intensity in low-energy-consumption areas, while the rebound effect in high-energy-consumption areas is not obvious or insignificant, which verifies the theory of "induced invention" put forward by British economist John Richard Hicks in 1932.

In order to test the estimation results of Model (5), this paper uses three methods to test the stability of panel residuals: the t-statistic of LLC, the t-statistic of Breitung and the w-statistic of IPS. The basic idea is that if the original assumption that the residuals have unit roots is rejected, then it shows that the residuals are stable. The results of specific tests are shown in Table 7.

Table 7. Model (5) Residual Stability Test of Dynamic Panel.

	LLC	**Breitung**	**IPS**
China	−4.4658 (0.0011)	−10.8711 (0.0000)	−11.2315 (0.0000)
Low-energy-consumption areas	−6.4861 (0.0000)	−7.1268 (0.0000)	−9.4585 (0.0000)
Middle-energy-consumption areas	−10.6855 (0.0000)	−7.9887 (0.0000)	−8.8421 (0.0000)
High-energy-consumption areas	−5.1235 (0.0003)	−8.0392 (0.0000)	−10.2877 (0.0000)

Note: The *p*-value of the coefficient is in parentheses.

The results in Table 7 show that regardless of the region or the magnitude of the energy intensity, the unit root test results of the panel residuals reject the null hypothesis at the 1% significant level, that is, the residual of the dynamic panel data Model (5) is stable and the setting of Model (5) is reasonable. Therefore, the estimation results of Model (5) using the analysis methods of SYS-GMM are also robust.

8. Discussion

The empirical results of this paper show that the improvement of industrialization and urbanization will lead to the increase in the regional energy intensity. However, urbanization has no significant impact on low-energy-intensity areas, but it has obvious impact on high-energy-intensity areas. This is completely consistent with the research conclusions of Samouilidis and Mitropoulo [2] on industrialization to enhance energy intensity and Wei et al. [7] on urbanization to enhance energy intensity. In addition, the energy intensity of the previous period, the regional economic development level, the energy price and technological innovation all have different influences on China's energy intensity, there is a rebound effect of technological innovation in China, and the energy price has an induced effect on technological innovation. When the cross term of the energy price and technological innovation level is added into the model, except for the energy price variable, the symbols, coefficients and significance levels of the other variables do not show great changes, which also indicates that the empirical results of this paper are robust. This is not completely consistent with the research conclusions of Wang Keying and Zhang Hongwu [25], especially in terms of regional heterogeneity. The reason is that the regional division is often divided into the east, the middle and the west according to the level of economic development. This paper is divided according to the energy intensity, that is, it is divided into low-energy-consumption areas (10 provinces), high-energy-consumption areas (10 provinces) and medium-energy-consumption areas (10 provinces). According to the results of the empirical analysis, it is not difficult to determine that policies seem to be in a dilemma of conflicting with each other. To promote high-quality economic development, industrialization and urbanization must be accelerated, and the upgrading of industrialization and urbanization will inevitably lead to the upgrading of the energy intensity. Therefore, it is necessary to enhance the connotation and development quality of industrialization and urbanization, promote new resource-saving and environmentally friendly methods of industrialization and urbanization, and accelerate the synchronous scientific development of new industrialization, informatization, urbanization and agricultural modernization.

9. Conclusions and Policy Implications

Through the study of the dynamic effects of industrialization and urbanization on energy intensity, especially the analysis of the differences in energy intensity among regions, it can be concluded that energy intensity increases with the increase in energy intensity, industrialization level and urbanization level in the early stage, but with the improvement of economic development level, the continuous rise in energy prices and the continuous innovation of technological level, the impact of the same factors on the energy intensity in different regions is also different.

At present, China is still in the stage of rapid industrialization and industries generally have high energy intensity, so the improvement of the industrialization level in various regions will inevitably increase the energy intensity. Although urbanization has no significant impact on the energy intensity in regions with low energy intensity, the improvement of the urbanization level in regions with medium and high energy intensity will increase the energy intensity. Obviously, industrialization and urbanization jointly promote the increase in energy intensity. At the same time, the level of economic development, energy prices and technological innovation are also reasons for the differences in energy intensity among regions. Therefore, in order to curb the growth of energy intensity, equal attention must be paid to the positive effects of industrialization and urbanization on energy intensity. The internal quality of industrialization and urbanization must be improved at the time of carrying out technological innovation, promoting high-quality development and increasing income. Especially in the western region, government must promote new methods of industrialization and urbanization that are resource-saving and environmentally friendly. According to these research conclusions, the following recommendations are given:

9.1. Encouraging Technological Innovation and Improving the Utilization Efficiency of Energy Intensity

Especially in areas with high energy intensity, with the improvement of industrialization and urbanization, the demand for energy intensity will increase. In the short term, it is not realistic to directly limit the demand and use of energy intensity. Therefore, improving the utilization efficiency of the energy intensity through technological innovation is an inevitable choice to achieve economic development and to transform the mode of economic growth. At present, there is still a big gap between China's technological innovation level and that of developed countries. In the future, relying on technological innovation and adopting new forms of energy to develop energy-saving technologies are undoubtedly the fundamental steps to improving the efficiency of energy intensity.

9.2. Optimizing the Industrial Structure of the Industrial Sector; Increasing the Proportion of the Tertiary Industry

Industry is a production sector with a high energy intensity. Among the factors affecting energy intensity, industrialization has naturally become the main factor leading to the increase in energy intensity. Therefore, it is necessary to accelerate the optimization of the industrial structure in the industrial sector, gradually reduce the proportion of industries with a high energy intensity such as the ferrous metal industry, metallurgy, and the chemical industry, and vigorously develop manufacturing industries with a low energy intensity such as the electronics, information, and service industries. With the acceleration of urbanization in China, the tertiary industry will certainly become an important industry to promote China's economic development. However, the role of the tertiary industry in reducing energy intensity has not been fully developed. Therefore, China must focus on the development of the tertiary industry, and accelerate the development of the tertiary industry, such as the service industry, by improving the supply quality of the service industry and the innovation of the service industry system.

9.3. Constructing a Green Manufacturing System to Promote the Coordinated Scientific Development of "Five Modernizations"

The rapid development of industry will not only increase the pressure on energy demand, but also reduce energy efficiency due to the extensive development characterized by a large amount of resources. We should adhere to the concept of "green mountains and rivers are gold and silver mountains", accelerate the construction of a green manufacturing system characterized by high efficiency, cleanness, low carbon and circulation, and promote the coordinated scientific development of new industrialization, informatization, urbanization, agricultural modernization and greening. At the same time, it is necessary to fully consider the differences and development of different regions, different industries, and different scale enterprises, to study and formulate differentiated policies for industrial energy conservation and emission reduction, to reduce energy consumption and environmental pollution, and to reduce energy intensity.

9.4. Advocating the Concept of Energy-Saving Lifestyle and Encouraging Consumption Behavior

With the continuous improvement of the level of economic development and the acceleration of urbanization, the production and living energy-consumption level of urban and rural residents in China has also been gradually improved. People's demand for durable consumer goods such as housing, transportation and household appliances has reached a climax, which undoubtedly directly or indirectly increases consumers' consumption of energy, leading to an increase in energy intensity. Therefore, we should actively advocate and encourage the consumption mode to achieve sustainable development, establish an energy-saving security system, and publicize and guide through appropriate policies to guide the transformation of consumer behavior to energy-saving. For example, the construction of small-scale utility buildings, the vigorous promotion of energy-saving transportation, and the research and development of environmentally friendly household appliances.

9.5. Forming a Reasonable Energy Price System to Achieve Market-Oriented Energy Price

Increasing energy prices can reduce China's energy intensity, and because of the "induced" impact of energy prices on technological innovation, this effect is very significant in low-energy-intensity areas. Therefore, the Chinese government should take reasonable macro-control measures to relax the regulation of energy prices, give full play to the role of energy prices on energy efficiency, and reduce the intensity of energy consumption. At the same time, the governance cost of the environmental pollution caused by the intensity of energy consumption should be incorporated into the energy price in order to internalize the external cost, improve the efficiency of energy use in China, and finally build a reasonable energy price system.

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