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Direct and Indirect Effects of Urbanization on Energy Intensity in Chinese Cities: A Regional Heterogeneity Analysis

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Abstract: Energy intensity reduction has become a constrained target from the 11th five-year plan in China. Energy consumption is expected to increase because of rapid urbanization and economic growth, whereas energy intensity reduction is regarded as a method to alleviate the pressure of growing energy demand. An important contribution of this study is the investigation of urbanization impact on energy intensity across China at the urban level. This research uses a balanced panel data set of 224 cities for the period between 2005 and 2016 and reports deep insights into and innovative findings for the reduction of energy intensity across different regions and cities in China. To examine the direct, indirect, and total effects and regional heterogeneous effects, we employ spatial Durbin models and spatial decomposition techniques. It reveals significant and negative direct effects of urbanization in the western and full regions. However, the indirect and total effects of urbanization are significantly negative in the eastern and western regions. The pressure of urbanization on energy has alleviated and is reversing, especially under the construction of people-oriented and green new-type urbanization. The empirics highlight industrialization as a contributing factor for high energy intensity in the spatial outcomes of regional analysis. The direct effect of per capita GDP supports the existence of the inverted U-shaped relationship between economic development and energy intensity. The study proposes fruitful implications to construct new-type urbanization for energy conservation and sustainable development in China.

Keywords: energy intensity; urbanization; spatial autocorrelation; regional heterogeneity; Chinese cities

1. Introduction

China has been the largest energy consumer since 2009 [1]. Its energy structure is dominated by coal, with the problems of energy shortage, energy security, and environmental pollution becoming severe. Energy is an indispensable input in production and is pivotal to sustainable development due to the scarcity and non-renewability of fossil fuels [2]. Energy efficiency is considered one dimension of energy security [3]. Improving energy efficiency is recognized as a cost-effective way to alleviate the energy shortage, environmental damage, and sustainable development problems brought by energy consumption [4] and to achieve sustainable development [5]. Ang [6] stated that energy intensity is a useful indicator of carbon emission and climate change. Reducing energy intensity is regarded as an efficient and effective way to mitigate energy shortage [7]. Against the backdrop of climate change, peak oil, and energy security, the central government of China has realized the urgent necessity for energy conservation and carbon emission reduction. The Chinese government implements an energy development strategy, setting conservation as its primary focus. The government has also made energy intensity as its restricted target in its 11th five-year plan (2006–2010). The evolution of energy intensity and its determinants in China are of great interest to researchers and the government [8,9], among which urbanization has caused much concern [10].

As stated by Joseph Eugene Stiglitz, the Nobel Laureate, urbanization in China and high-tech development in the USA are the two key issues affecting the 21st century. Urbanization is an impetus for economic growth in China and can increase energy use, especially from lifestyle improvement, infrastructure construction, and transportation, including long distance commuting [11]. China has undergone an unprecedented urbanization process after 1978 [12]. City is the main areas for human activities and the per capita energy consumption of urban residents is approximately six times of that consumed by rural residents in China [13]. Considering energy conservation task from the perspective of urban development is necessary to implement sustainable urban construction. In March 2014, the Central Committee of the Communist Party of China (CPC) and the State Council jointly released a "National New-Type Urbanization Plan (2014–2020)". The concept of new-type urbanization stresses people-oriented and environmentally-friendly construction of cities to alleviate the effect of urbanization on energy consumption [14]. The effect of urbanization on energy consumption and energy intensity is of interest to researchers due to its importance in sustainable development [11]. Predicting high energy demand from cities due to the increased construction of new-type urbanization is reasonable, but the growth of energy demand can be alleviated by efficiency improvements brought about by advanced technology and upgraded economic structure [15]. Therefore, the net effect of urbanization on energy intensity requires timely study.

This research aims to evaluate the role of cities in curbing energy intensity by adopting the spatial Durbin model (SDM) which helps improve the prediction accuracy and contributes to regional sustainability at the national scale. The reminder of this study is structured with four sections. Section 2 provides a brief review of the literature on the relationship between urbanization and energy intensity (efficiency) from the global and Chinese perspectives. Section 3 describes the modeling process and data processing. Section 4 reports the empirical results. Section 5 presents the conclusion and policy implications.

2. Literature Review

Studies on energy consumption and urbanization are abundant [16–19], but research on the relationship between energy intensity and urbanization is rare and needs further investigation [20] particularly at the urban level. Energy efficiency improvement is considered a cost-effective way to alleviate problems caused by energy shortage [4]. To alleviate energy shortage and control energy consumption brought about by urbanization, finding out how energy efficiency or intensity evolves during urbanization, or whether energy efficiency improves during urbanization [21]. However, the impact of urbanization on energy intensity or efficiency is undetermined, which is contributed by two interdependent forces of urbanization. On one side, energy is necessary in economic development, industrialization, and society. Urbanization pushes energy consumption through the demand from residential, infrastructure, transportation and building construction, especially the energy intensive activities. On other side, urbanization contributes to economies of scale in production, and promotion of more efficiently energy usage than rural areas [22,23]. In terms of the empirical study on the interdependence between urbanization and energy intensity worldwide, the pioneer work of Sadorsky [22] finds no strong relationship between energy intensity and urbanization among 76 developing countries during the period 1980–2010. The influence of urbanization on energy intensity varies in 10 Asian countries [20]. Belloumi and Alshehry [24] report the positive impact of urbanization on energy intensity in the short and long term in Saudi Arabia over the period 1971–2012. Farajzadeh and Nematollahi [25] reveal the significant role of urbanization on energy intensity reduction.

Due to the importance of urbanization in the Chinese economy and its increasing energy consumption, the case of China is given emphasis. The empirical study on urbanization and energy intensity (efficiency) of China is pioneered by the work of Song and Zheng [23] by using the data of 28 provinces from 1995 to 2009. They highlight significant positive impact of urbanization and attribute the result to the function of attracting energy intensive industry in urban areas. The research of Yan [26] that covers 30 provinces from 2000 to 2012 shows the impact of urbanization is positive on not only aggregated energy intensity but also on two disaggregated intensities (electricity and coal intensity). Using an unbalanced data set of 30 provinces from 1986 to 2011 and considering cross sectional dependence and slope heterogeneity, Ma [21] confirms that urbanization drives energy and electricity intensities in most cases, but the result for carbon intensity is ambiguous, and province-specific energy policy is suggested. The work of Liu and Xie [27] covers a time series in China from 1978 to 2010 and reveals a nonlinear long-term relationship running from urbanization to energy intensity. Elliott et al. [28] find that the negative effect of urbanization on energy intensity works through the construction sector. Using the Panel Vector Autoregression model, Lin and Zhu [10] estimate the relationship among urbanization, energy intensity, and carbon intensity in China's 30 provinces from 2000 to 2015. They report an inverted U-shaped effect of urbanization on energy intensity. Huang and Yu [29] state that the effect of urbanization on energy intensity is complex and reports positive, insignificant, and negative effects for the eastern, central, and western regions respectively. Salim et al. [30] argue that the effect of urbanization on energy intensity in China is less significant than that in India due to the technologies recently applied and invested in clean coal and renewable energy. In brief, no concrete findings, which may be caused by sample, method, spatial scale, and indicator, exist for energy efficiency. Energy intensity, which is considered the opposite of energy productivity, is only a single indicator for energy efficiency or energy productivity, and is commonly used due to easy calculation. Moreover, the concern for total factor energy efficiency is increasing. The study by Lv et al. [31] is one of the rare studies on the relationship between urbanization and total factor energy efficiency; the research uses provincial data from 2001 to 2010 and spatial panel models to assess the effect of urbanization. Du et al. [32] also focus on total factor energy efficiency. Using the data of 30 provinces from 2006 to 2015 and stochastic frontier models, they find that urbanization plays a significant role in reducing energy efficiency. Whatever selected indicator is, the results are still mixed. The main empirical studies are listed in Table 1.

Table 1. Summary of recent literature regarding the impact of urbanization on energy intensity/efficiency.

Author	Period	Sample	Methodology	Main Results
Part A—Worldwide research				
Sadorsky [22]	1980 to 2010	76 countries	POLS, FE, MG	URB→EI: Mixed
Belloumi and Alshehry [24]	1971 to 2012	Saudi Arabia	ARDL, GC, FMOLS, DOLS	URB→EI: significantly positive
Bilgili, Koçak, Bulut and Kuloğlu [20]	1990 to 2014	10 Asian countries	PMG	URB→EI: Negative (both LR and SR)
Farajzadeh and Nematollahi [25]	1973 to 2013	Iran	Regression, ANN	URB→EI: significantly negative
Part B—Research related to China				
Song and Zheng [23]	1995 to 2009	28 provinces	Fisher ideal index method, FE	insignificant
Liu and Xie [27]	1978 to 2010	National, regional	Non-linear cointegrating and GC, TVECM	URB→EI: Mixed
Yan [26]	2000 to 2012	30 provinces	Fixed Effects, FGLS, PCSE, DK.	URB→EI/EEI/COI: positive
Ma [21]	1986 to 2011	30 provinces	CCEMG, AMG	URB→EI/EEI: positive; UR→COI: no
Huang and Yu [29]	2004 to 2013	27 provinces	PCSE, FE	URB→EI: mixed
Lv, Yu and Bian [31]	2001 to 2010	31 provinces	DEA; SAR, SEM	URB→TFEE: mixed
Elliott, Sun and Zhu [28]	1995 to 2012	30 provinces	MG, AMG	URB→EI: mixed
Lin and Zhu [10]	2000 to 2015	30 provinces	PVAR	URB→EI: inverted U-shaped effect
Du, Wang and Zhang [32]	2006 to 2015	30 provinces	TFEE, SFA	URB→energy inefficiency: positive
Salim, Rafiq, Shafiei and Yao [30]	1980 to 2010	13 Asian countries including China	ARDL	URB→EI: insignificant

POLS = pooled OLS, FE = fixed effects, RE = random effects, FGLS = feasible generalized least squares, PCSE = linear regression with panel-corrected standard errors, DK = linear regression with Driscoll–Kraay standard errors, ARDL = autoregressive distributed lag bounding test, DOLS = dynamic OLS, (P)VAR = (panel) vector autoregressive regression, TVECM = (threshold) vector error correction model, AMG = augmented mean group, (P)MG = (pooled) mean group, SLM = spatial lag model, SEM = spatial error model, ANN = artificial neural networks, GC = Granger causality test, TFEE = total factor energy efficiency, SFA = stochastic frontier analysis, DEA = data envelopment analysis.

Poumanyvong and Kaneko [33] summarize the studies on urbanization and energy consumption on the basis of the data at national, city, and household levels. The administrative division in China is hierarchical and urbanization occurs at national, provincial, and urban levels. Due to data availability, previous studies on the relationship between urbanization and energy intensity mostly focus on national or provincial scale data [21,26]. Prefectural cities have power to make specific urbanization, energy, and investment invitation policies according to their economic development and resource endowment [34]. For example, urbanization plans between cities may be different due to their location and open-up policies, such as cities located in inland or coastal areas. Energy policy is implemented by low-level government, with restricted energy consumption or intensity policy published and set to provinces in a five-year plan by the Nation Bureau of State but disaggregated to cities by provincial government. National- or provincial- level study ignores the heterogeneity experienced by cities that may conceal the differences among cities and lead to biased estimates [35,36]. Preceding research on urbanization [37] or energy [34,38] has considered data at the urban level, but it lacks evidence for the relationship between urbanization and energy intensity at urban level. Therefore, how does urbanization affect energy intensity in Chinese cities? Does this effect show similar results to those in the provincial level? These questions can demonstrate detailed and accurate evidence.

On basis of the debates reviewed above, the present study set out to expand the current literature from the following three views. First, the research highlights the role of cities in constraining energy intensity by using the data of 224 cities in China. One important reason for the inconsistent results with previous literature may be the defined spatial scales, which conceal the heterogeneity and dependence among cities within a specific province. Accordingly, the study provides an in-depth and innovative empirical understanding by conducting a regional analysis of cities via advanced spatial techniques. For the empirical analysis, we code the city-level data of energy intensity and urbanization from several channels and sources. Urban level data are rarely explored in China due to the lack of statistical publications and complicated collection. To the best of the authors' knowledge, the present study is the first to investigate the relationship between urbanization and energy intensity at an urban level, thus revealing the role of cities in energy conservation and sustainable urban construction. The motivation behind this urban-level analysis is justified by the fact that urban areas and metropolitan cities contribute a significant proportion of the economic growth and revenue of the country. In addition, energy consumption in urban areas is six times that of rural areas [13]. Liddle and Lung [39] also indicate that urbanization is a measure of local level, as opposed to the national level, and is considered a good indicator for spatial density.

Secondly, the study reveals the direct and indirect effects of urbanization on energy intensity. As urbanization may affect energy intensity in the local areas, it also influences the energy consumption behavior of surrounding regions, thus implying the potential spatial spillover (or indirect) effects of urbanization. To address and decompose the direct and indirect effects of urbanization, spatial panel models are preferred in this study. A balanced urbanization process in such an expansive country is determined by complicated socio-economic interactions or inter-dependence between provinces and regions, which may share common shocks, opportunities, challenges, and constraints [21,31]. Economic activities, such as inter-regional trade, energy transportation, technology spillover, regional competition, and countrywide policy on energy intensity restrictions among regions cannot be ignored. Some of these processes may exhibit remarkable demonstration and catch-up effects spatially and temporally, which means that a successful project or good policy will have a massive influence on neighboring provinces or regions, either immediately or in the near future. Thus, assuming spatial dependence among cities is reasonable, suggesting a spatial analysis [7,31]. Most previous analysis has developed panel data modeling method to deal with cross sectional dependence [21], which cannot deal with the presence of spatial autocorrelation in the data set and may produce biased results [40], only revealing the direct effect of urbanization.

Lastly, the research examines the spatial heterogeneity among cities in China that help determine the inequality of regional development and the heterogeneous role in energy conservation. China is a vast country with disparities in resource endowment and incomes, which creates heterogeneous regional effects of urbanization on energy intensity [27,29]. There are some official divisions of provinces (or cities) and different policies for regions—i.e., inner region economic policy in China, western development strategy—which can cause unbalanced urbanization [21]. Seldom has research paid attention to spatial heterogeneity with consideration of spatial autocorrelation within the divided regions [7,41]. In the present study, the full sample is separated into three sub-samples—including eastern, central, and western regions—and spatial models are developed for each sub-sample. Determining whether heterogeneous effects exist among regions is important to establish regionally-specific urbanization and energy policy, both of which help achieve balanced development. This study is motivated by the recent energy issues in China and aims to provide fruitful implications for reducing energy intensity in a more disciplined and innovative manner, without harming economic progress.

3. Methodology and Data

3.1. Empirical Method

Energy intensity is diversified among cities in China but may be spatially dependent due to geographical proximity, socio-economic interactions, and common shocks, such as production technology, similar preference for home appliance, and energy conservation policy. The spatial autocorrelation of energy intensity is considered in spatial panel models by incorporating spatial effects. These models help derive more accurate and unbiased results than traditional panel models. In addition, distinguishing direct and indirect effects of independence, which has been acknowledged and adopted in the area of energy efficiency, is useful [31,42,43].

A series of spatial models (such as SDM, spatial lag model, or spatial error model), which can be developed for defined objectives, exists. To produce a convincible result, the procedure for spatial modeling follows the specification rule of the general-to-specific and specific-to-general rules [44]. We first calculate Moran's I and Geary's C indexes to determine whether spatial autocorrelation exists in energy intensity.

The global Moran's I index and Geary's C indexes are defined as follows:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \tag{1}$$

$$C = \frac{(n-1)\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - x_j)^2}{2\left(\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\right)\left[\sum_{i=1}^{n}(x_i - \overline{x})^2\right]} \tag{2}$$

where x_i (x_j) is the energy intensity in region i (j); w_{ij} represents element of spatial matrix W which is constituted by decaying distance among regions. $S^2 = \frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n}$. $I > 0$ indicates a positive spatial autocorrelation, thus a high (low) value is surrounded by high (low) values. By contrast, $I < 0$ indicates a negative spatial autocorrelation, thus a high (low) value is surrounded by low (high) values. Geary's C index moves to the opposite direction from Moran's I index.

Then, SDM is established to estimate the impact of urbanization on energy intensity.

$$\begin{aligned} EI_{it} = {} & \delta \sum_{j=1}^{N} w_{ij} \times EI_{jt} + \beta_1 urbanization_{it} + \theta_1 \sum_{j=1}^{N} w_{ij} \times urbanization_{jt} \\ & + \beta^c X_{it}^c + \theta_c \sum_{j=1}^{N} w_{ij} \times X_{jt}^c + \mu_i + \varepsilon_{it} \end{aligned} \tag{3}$$

In this model, *EI* represents energy intensity. *X* indicates the selected control variables. Coefficient θ_1 represents the spatial spillover effect of urbanization on energy intensity. Spatial specific effect μ_i may be treated as a random or fixed effect, which is tested by Hausman test. In addition, the spatial Durbin model can be simplified. If $\theta = 0$, SDM can be simplified into a spatial lag model. If $\theta + \delta\beta = 0$, SDM can be simplified into a spatial error model. Wald and likelihood ratio tests are performed in this study to check the two kinds of null hypotheses: $\theta = 0$ and $\theta + \delta\beta = 0$.

Finally, the coefficient in spatial models is biased due to the effect of feedback loops. To derive an accurate estimator for spatial spillover effect, the spatial decomposition technique proposed by LeSage and Pace [45] is adopted to calculate the direct, indirect (which is the spatial spillover effect) and total effects. Direct effect measures the average extent of how a dependent variable in one region changes when an independent variable in the local region changes. Indirect effects represent the average response of dependent variable to the change of an independent variable from neighborhoods. The total effect is the sum of direct and indirect effects.

$$direct_r = \frac{\sum_{i=1}^{n} S_r(W)_{ii}}{n} = \frac{tr[S_r(W)]}{n} \tag{4}$$

$$total_r = \frac{\tau'_n S_r(W)\tau_n}{n}, \quad indirect_r = total_r - direct_r \tag{5}$$

where $S_r(W)$ is defined as the partial derivative of dependent variable y at location i with respect to the r-th exogenous variable at location j.

$$\frac{dy}{dx_r} = S_r(W) = (I_n - \delta W)^{-1}(I_n\beta_r + W\theta_r) \tag{6}$$

3.2. Data Processing

In SDM (3), seven variables (C = 7) are selected as control variables, including per capita GDP (PERGDP) and its quadratic term (PERGDP2), industrialization (IND), proportion of tertiary industry value added to GDP (TER), foreign direct investment (FDI), international trade (TRADE), and energy price (PRICE). Economic growth is recognized as an important factor of energy consumption [46]. Per capita GDP has been extensively studied in energy intensity [22,47]. The effect of per capita GDP is recognized as nonlinear and presents an environmental Kuznets or inverted U-shaped curve [20]. Therefore, the quadratic term of per capita GDP is added in the right-hand side of the model. Industrialization (proportion of industry value added to GDP) is an accompanying process of urbanization and is the impetus of economic development [23]. Secondary industry is energy intensive and is the largest energy consumption sector [48]. It is regarded as the main cause of energy intensity increase [21]. Industrial structure upgrading is an economic development policy in China which induces an industry-led economic growth pattern, and China has given more emphasis on energy conservation during industry transformation and upgrading [49]. As another aspect of economic structure, the share of tertiary value added in GDP is included [38,50]. Tertiary industry less energy intensive than secondary industry [51]. It is expected to decrease energy intensity following economic development because the experience of economic development in industrialized countries shows an industry transition from primary to secondary to tertiary. The proportion of tertiary industry is increasing in many cities due to service demands arising from urbanization. FDI is one method of technology transfer from abroad [29,38]. The effect of FDI can be decomposed into scale and technique effects [34,52]. The effect of FDI on energy intensity is interacted with income and industrialization [53]. FDI is converted to RMB by exchange rate, and its proportion in GDP is calculated as an indicator. International trade has been increasing since the open-door policy of China in 1978. Trade affects energy directly by energy trade and indirectly by energy embodied in products. It is also one means of international technology spillover. Zheng et al. (2011) confirm the driving forces of increasing trade on energy intensity. Yu (2012) finds no significant effect of export. The indicator for international trade is calculated as the proportion of import and export to GDP. Energy pricing is a signal reflecting energy supply and demand and has power to push enterprises to choose clean energy and energy-efficient technology and equipment [54]. Due to government intervention in the energy market, energy prices are relatively low in China [9]. The central government has made some policies to improve energy price marketization. The purchase price index of fuel and power of the corresponding province is used as a proxy for energy price.

Data set in this study is a balanced panel, including 224 prefectural level and above cities in China from 2005 to 2016, covering 20 provinces, which is collected from all possible public channels to include as many cities as possible. Although there are 293 prefectural level and above cities, data for energy intensity and urbanization are incomplete due to their data disclosure policies and statistical quality. The cities are divided into three groups, including 85 cities of 9 provinces in the eastern region, 82 cities of 6 provinces in the central region, and 57 cities of 5 provinces in the western region (as illustrated in Figure 1, the eastern, central, and western regions are colored orange, green, and blue, respectively), covering main parts of three regions. Data for northeast region, Qinghai, Tibet, and Xinjiang are totally excluded due to unavailability. Data for cities starts in 2005, because China began making policies on energy intensity and requiring local government to publish data on energy intensity during its 11th five-year plan (2006–2010). Energy intensity data are obtained from the provincial Statistical Yearbooks (2006–2017), the provincial Statistical Bulletin of Energy Consumption Indicators (2006–2017), annual Statistical Bulletin on National Economic and Social Development of cities, and newspapers. Two statistical calibers for urban population exist in China. One is residential population of urban areas, and the other is non-agricultural population defined by the 'hukou registration' of China. Urbanization in this study is defined as the percentage of urbn residential population to the total population due to data availability. Data for urbanization is collected from provincial and urban Statistical Yearbooks (2006–2017), annual Statistical Bulletin on National Economic and Social Development of cities, government news, and related literature on individual cities. Data for control variables are collected from China City Statistical Yearbook (2006–2017) and provincial and urban Statistical Yearbook (2006–2017). To avoid the effect of inflation, gross regional production is adjusted to the constant price of the base period 2005. All variables are transformed into logarithms to alleviate heterogeneity, reduce the order of magnitude, and gain elasticity. Summary statistics of these variables for each sample are presented in Table 2, which clearly demonstrates that the eastern region has highest average level of urbanization and economic development but the lowest average energy intensity.

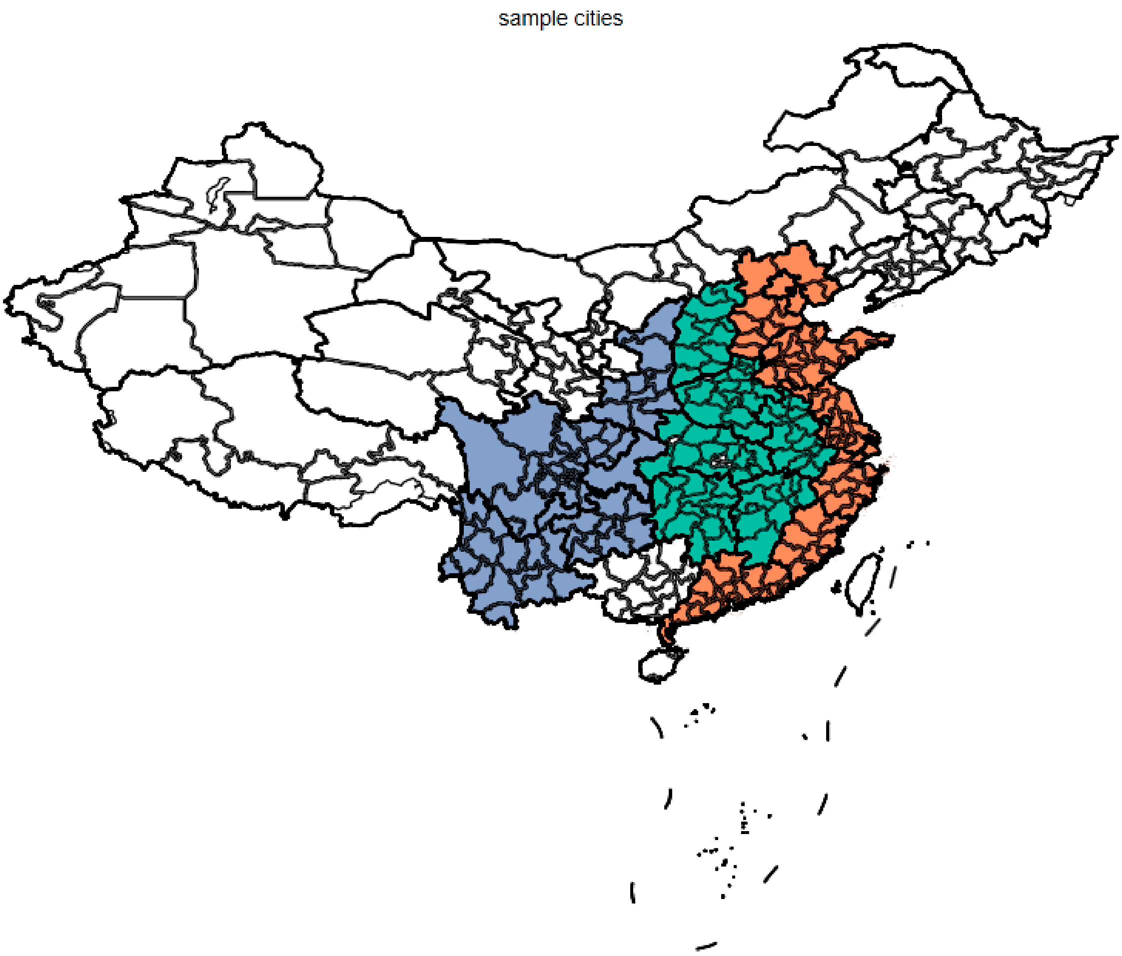

Figure 1. Prefectural level and above cities selected in sample.

Table 2. Summary statistics.

Sample	Variables	Mean	SD	Min	Median	Max
Full Obs. = 2688 N = 224	EI	0.140	0.457	−1.050	0.122	2.168
	URB	3.823	0.311	2.809	3.826	4.605
	IND	3.871	0.215	2.929	3.900	4.410
	TER	3.593	0.222	2.484	3.590	4.385
	PERGDP	9.533	0.616	8.059	9.464	12.221
	PERGDP2	91.249	11.899	64.950	89.573	149.347
	FDI	0.205	1.387	−8.163	0.330	8.159
	TRADE	2.058	1.673	−5.005	2.081	11.764
Eastern Obs. = 1020 N = 85	EI	−0.113	0.429	−1.050	−0.163	1.543
	URB	4.001	0.258	3.333	3.983	4.605
	IND	3.900	0.168	2.958	3.918	4.410
	TER	3.669	0.201	2.609	3.657	4.385
	PERGDP	9.965	0.553	8.538	9.897	12.221
	PERGDP2	99.606	11.115	72.894	97.945	149.347
	FDI	0.576	0.931	−2.464	0.604	2.457
	TRADE	3.270	1.053	−0.206	3.202	6.701

Table 2. *Cont.*

Sample	Variables	Mean	SD	Min	Median	Max
Central Obs. = 984 N = 82	EI	0.258	0.406	−0.777	0.207	1.459
	URB	3.797	0.242	2.927	3.794	4.437
	IND	3.893	0.219	3.056	3.923	4.314
	TER	3.548	0.207	2.847	3.554	4.210
	PERGDP	9.396	0.471	8.175	9.380	10.636
	PERGDP2	88.510	8.899	66.830	87.984	113.120
	FDI	0.570	1.154	−4.571	0.558	8.159
	TRADE	1.719	1.403	−1.527	1.554	11.764
Western Obs. = 684 N = 57	EI	0.350	0.387	−0.462	0.305	2.168
	URB	3.594	0.311	2.809	3.595	4.315
	IND	3.797	0.253	2.929	3.805	4.396
	TER	3.546	0.243	2.484	3.552	4.114
	PERGDP	9.084	0.459	8.059	9.047	10.351
	PERGDP2	82.728	8.422	64.950	81.839	107.148
	FDI	−0.871	1.675	−8.163	−1.040	5.033
	TRADE	0.737	1.554	−5.005	0.768	4.781

"Obs." is the number of observations. "N" is the individual number of cities selected.

4. Empirical Results and Discussion

4.1. Spatial Autocorrelation Tests

Table 3 lists the Moran's I and Geary's C indexes of energy intensity of the sample cities from 2005 to 2016. As indicated in Table 2, the spatial autocorrelation indicators, Moran's I and Geary's C, exhibit significantly positive values. Thus, energy intensity demonstrates evident spatial agglomeration effects because cities with high (or low) consumption values are clustered together. The trend of Moran's I index is fluctuating but increasing on the whole, indicating the tight spatial autocorrelation of energy intensity among cities. The positive spatial autocorrelation confirms the hypothesis of spatial dependence of energy intensity among cities, thus contributing to technology spillover, factor transportation, and imitated consumption preferences caused by convenient socio-economic interactions among neighbors. The study adopts spatial panel models, which consider spatial effects to analyze the effect of urbanization on energy intensity.

Table 3. Global Moran's I and Geary's C index of energy intensity from 2005 to 2016.

	Full		East		Central		West	
Year	**Moran's I**	**Geary's C**	**Moran's I**	**Geary's C**	**Moran's I**	**Geary's C**	**Moran's I**	**Geary's C**
2005	0.077 ***	0.907 ***	0.101 ***	0.905 **	0.120 ***	0.833 ***	0.041 ***	0.987
2006	0.079 ***	0.905 ***	0.102 ***	0.905 **	0.129 ***	0.823 ***	0.043 ***	0.986
2007	0.081 ***	0.903 ***	0.103 ***	0.900 **	0.125 ***	0.827 ***	0.045 ***	0.985
2008	0.082 ***	0.902 **	0.098 ***	0.903 **	0.120 ***	0.833 ***	0.044 ***	0.986
2009	0.104 ***	0.885 ***	0.100 ***	0.901 **	0.107 ***	0.852 ***	0.058 ***	0.933 **
2010	0.101 ***	0.889 ***	0.108 ***	0.894 ***	0.102 ***	0.859 ***	0.057 ***	0.934 **
2011	0.104 ***	0.886 ***	0.111 ***	0.891 ***	0.103 ***	0.858 ***	0.058 ***	0.933 **
2012	0.104 ***	0.885 ***	0.115 ***	0.890 ***	0.103 ***	0.855 ***	0.062 ***	0.929 **
2013	0.106 ***	0.882 ***	0.114 ***	0.890 ***	0.108 ***	0.848 ***	0.065 ***	0.927 **
2014	0.100 ***	0.885 ***	0.089 ***	0.933 **	0.114 ***	0.830 ***	0.060 ***	0.929 **
2015	0.1041 ***	0.885 ***	0.092 ***	0.928 **	0.124 ***	0.819 ***	−0.009	0.984
2016	0.099 ***	0.887 ***	0.087 ***	0.934 **	0.126 ***	0.817 ***	−0.020	0.992

The superscripts ***, **, and * indicate that the coefficient is statistically significant at the 1%, 5%, and 10% levels.

4.2. Empirical Results of Spatial Durbin Models

This section highlights the empirical results, which analyze the role of urbanization, industrialization, the proportion of tertiary to GDP, FDI, trade, per capita GDP, and its quadratic term on energy intensity. Table 4 reports the results of spatial Durbin panel models. The four columns in the table represent the results of spatial panel models based on data of the full sample, eastern, central, and western regions of China. It contains three parts in this table, (1) direct or local effect, (2) indirect or spatial spillover effect (variables with spatial lagged, e.g., W × URB), and (3) diagnostic statistics. In accordance with the general-to-specific rule for developing a spatial panel model [44], a spatial Durbin model is constructed as a starting point, then the Wald test and log likelihood ratio test for spatial lag and spatial error are respectively used to verify whether the spatial Durbin model should be simplified to a spatial lag model or a spatial error model. As shown at the bottom part of Table 4, certain diagnostic tests for spatial Durbin models are presented. The Hausman test suggests whether a random spatial effect model is specified. The results of diagnostic tests suggest that spatial models with random spatial specific effects are selected in the full sample and the samples of eastern, central, and western regions under a significance level of 1%.

Table 4. Empirical results for spatial models.

EI	Full (N = 224)	Eastern (N = 85)	Central (N = 82)	Western (N = 57)
URB	−0.170 *** [0.03]	0.014 [0.06]	0.020 [0.05]	−0.558 *** [0.06]
IND	0.221 *** [0.03]	0.288 *** [0.07]	0.039 [0.05]	0.166 *** [0.05]
TER	0.198 *** [0.03]	0.217 *** [0.06]	0.103 ** [0.04]	0.190 *** [0.05]
PERGDP	0.480 *** [0.18]	1.042 *** [0.36]	−0.486 [0.37]	3.363 *** [0.48]
PERGDP2	−0.022 ** [0.01]	−0.051 *** [0.02]	0.030 [0.02]	−0.180 *** [0.03]
FDI	−0.007 *** [0.00]	−0.014 ** [0.01]	−0.009 * [0.00]	−0.003 [0.00]
TRADE	0.008 ** [0.00]	0.027 ** [0.01]	0.002 [0.01]	0.012 ** [0.00]
PRICE	0.002 [0.01]	0.189 * [0.11]	0.025 *** [0.01]	−0.578 *** [0.13]
constant	10.056 ** [4.10]	−7.187 [8.28]	−13.106 [9.70]	29.254 ** [14.67]
W × EI	0.610 *** [0.08]	0.685 *** [0.07]	0.564 *** [0.09]	0.456 *** [0.12]
W × URB	0.056 [0.19]	−0.762 *** [0.25]	−0.270 [0.22]	−0.390 * [0.22]
W × IND	0.287 [0.20]	−0.244 [0.30]	0.339 [0.28]	0.014 [0.23]
W × TER	−0.444 ** [0.20]	−0.230 [0.29]	−0.349 [0.24]	0.340 [0.26]
W × PERGDP	−2.203 *** [0.77]	0.739 [1.64]	3.865 * [2.00]	−9.952 *** [3.40]
W × PERGDP2	0.088 ** [0.04]	−0.026 [0.07]	−0.231 ** [0.11]	0.542 *** [0.19]
W × FDI	−0.058 *** [0.02]	0.003 [0.03]	−0.032 [0.02]	−0.025 [0.02]
W × TRADE	−0.008 [0.03]	0.022 [0.05]	0.013 [0.03]	0.077 ** [0.04]

Table 4. *Cont.*

EI	Full (N = 224)	Eastern (N = 85)	Central (N = 82)	Western (N = 57)
W × PRICE	−0.046 [0.04]	−0.242 * [0.13]	−0.105 *** [0.03]	0.896 *** [0.21]
Obs.	2688	1020	984	684
Hausman	40.46 (0.0011)	18.87 (0.3363)	14.91 (0.6022)	23.96 (0.1205)
Wald test−spatial lag	28.81 (0.0001)	41.00 (0.0000)	45.44 (0.0000)	56.28 (0.0000)
LR test spatial lag	51.09 (0.0000)	57.89 (0.0000)	64.13 (0.0000)	55.01 (0.0000)
Wald test−spatial error	40.56 (0.0000)	32.30 (0.0000)	45.71 (0.0000)	31.75 (0.0000)
LR test spatial error	73.32 (0.0000)	58.55 (0.0000)	75.61 (0.0000)	44.87 (0.0000)
R−square	0.8227	0.8055	0.8854	0.8132

Standard errors are reported in brackets. P values are presented in parentheses. The superscripts ***, **, and * indicate that the coefficient is statistically significant at the 1%, 5%, and 10% levels.

The coefficients of spatial lag energy intensity are significantly positive in four models, and this finding is consistent with that of Moran's I index [7,42]. Demonstration effect is found in different regions of China, and this effect may contribute to work commuting, inseparable consumption preference, common energy policy, and economic shock [21,40]. The regional analysis reveals that the magnitude of coefficients for the eastern region is higher than that for central and western regions, with elasticities of 0.689, 0.673, 0.469, indicating a tight spatial autocorrelation of energy intensity in the eastern region and implying the necessity of regional-specific energy conservation policies. Cities in the eastern region have many common socio-economic interactions due to convenient facilities, infrastructures. Therefore, spatial autocorrelation and regional heterogeneity exist in the energy intensity among regions [54].

The coefficients of urbanization are significantly negative in full (–0.170) and western (–0.558) samples. However, those in eastern and central regions are positive but insignificant. This finding is in line with that of Lin and Zhu [10] and Lv, Yu, and Bian [31]. However, the result is in contrast with Ma [21] and Yan [26], who find a significant positive relationship between urbanization and energy intensity in the full region. The contradicted result is caused by the selected sample period and regional heterogeneity. First, the central government of China has already set a constrained target for energy intensity in its 11th five-year plan. From then on, each city strives to achieve its energy conservation task and pays attention to energy-efficient urban construction. With the consciousness and policy guidance of energy conservation, insignificant and negative effects of urbanization on construction of people-oriented and green urbanization are expected. Second, the significant negative result in the western region may be caused by its lagging urbanization. The western region in China is not that developed, has lagging urbanization, and has a low economic development status, with a primary transformation process of energy pattern. The heterogeneous results among regions inspire us to discover the various impacts of urbanization at different urban development stages, which may result in a similar analysis with Ji and Chen [15]. Moreover, the spatial spillover coefficient of urbanization is only significantly negative in the eastern and western regions, indicating that the urbanization of certain cities helps reduce the energy intensity of other cities. In the eastern region, urbanization contributes to technology spillover and energy transportation and enhances the socio-economic interaction among cities. For simplicity and consistency, the spatial spillover effect is discussed in detail in the following section with an accurate estimation.

The coefficients of industrialization and tertiary industry have similar signs and significance levels and are analyzed in this study. Full sample estimation has affirmed a statistically significant and positive association with energy intensity. A similar result is presented for the eastern region, which reports a higher magnitude of elasticity than in central and western regions. For the western region, the coefficients are also significant and positive, but the estimations of the central region report positive but insignificant coefficient of industrialization. The results reveal that industrialization and energy demand from service sectors are significant causes of high energy intensity in China. Similar findings are reported by Sadorsky [22], Ma and Yu [38], and Huang, Du, and Hao [7], who also discover a positive and significant relationship between economic structure and energy intensity. Although the result for industrialization is expected due to the intensive energy use of secondary industry that for the tertiary industry is beyond expectation [38]. In the case of spatial spillover coefficient estimations, the spatial spillover effects from neighboring cities are insignificant for industrialization and tertiary, but one exception is the significantly negative result for tertiary industry in the full region. Therefore, industrial and service activities in one city have no significant pushing impact on the energy intensity of neighboring cities within regions. It exhibits a different result to Jiang and Ji [55] because cities have made diversified efforts toward energy conservation, given their disparity on industrialization and economic development.

As for the relationship between economic development and energy intensity, inverted-U shaped results are confirmed in all cases, but significant results are reported in full, eastern, and western regions. The findings explain that the more gross regional product tends to increase energy intensity at first and then decrease it. There is a threshold of per capita GDP, after which energy intensity can be reduced with increasing income, further indicating that in the long run, economic growth in China depends upon energy consumption and energy intensity tends to decrease.

Turning to the effect of FDI, it is noteworthy that FDI has negative local effects on energy intensity in all cases excepting the western region. Results are similar to that by Ma and Yu [38] which focuses on prefectural-city level data. In contrast to Jiang and Ji [55] and Song and Zheng [23], whereas the former uses per capita FDI as indicator. It indicates the effect of FDI is inconsistent in different research and may be affected by spatial scale, indicator, and sample period. The insignificant result in this study may be caused by the large unequal absorption ability to technique spillover among cities that is concealed when adopting provincial data. The spatial spillover effect of FDI is significantly negative only in the full sample. Note that the coefficients of trade are positive in contrast with Jiang and Ji [55], indicating international trade especially export, includes a large proportion of energy intensive products.

In addition, the impact of energy pricing on energy intensity is significantly positive in the eastern and central regions but significantly negative in the western region and insignificant in full sample [54]. This result is different from Huang and Yu [29] and Huang, Du, and Hao [7], who use provincial data and employ relative energy price as an indicator. The inconsistent result of energy pricing among regions may be induced by the disparity in endowment of energy. Energy dependence in the eastern region is high due to its high economic development although the eastern region has widely applied of energy-efficient equipment. The central region includes certain coal-producing area with abundant reserves. The western region is at the early stage of development and has considerable room to decrease energy cost and improve energy efficiency by turning to energy-efficient equipment and technology when energy prices increase. The spatial spillover effect of energy pricing is negative in eastern and central regions but significantly positive in the western region, suggesting that the energy market in the eastern and central regions is sensitive to countrywide pricing information due to its high energy demand.

4.3. Decomposition Analysis of Spatial Effects

As pointed out by LeSage and Pace [45], the point estimation of the coefficient may lead to erroneous conclusions. They also argued that introducing a partial derivative of a dependent variable to an independent variable is effective in interpreting spatial effects. By considering the feedback loop effects and to reveal the exact spatial spillover effects, the direct, indirect, and total effects of spatial models are decomposed. This method is used to conduct an in-depth analysis. The empirical findings of the decomposition analysis are displayed in Table 5.

Table 5. Results for decomposition of spatial effects.

EI	Full (N = 224)	Eastern (N = 85)	Central (N = 82)	Western (N = 57)
		Direct effects		
URB	−0.169 *** [0.03]	−0.013 [0.06]	0.018 [0.05]	−0.570 *** [0.06]
IND	0.223 *** [0.03]	0.283 *** [0.07]	0.044 [0.05]	0.165 *** [0.05]
TER	0.196 *** [0.03]	0.216 *** [0.06]	0.098 ** [0.04]	0.202 *** [0.05]
PERGDP	0.459 *** [0.17]	1.099 *** [0.36]	−0.403 [0.37]	3.165 *** [0.49]
PERGDP2	−0.021 ** [0.01]	−0.053 *** [0.02]	0.025 [0.02]	−0.169 *** [0.03]
FDI	−0.007 *** [0.00]	−0.014 ** [0.01]	−0.009 ** [0.00]	−0.003 [0.00]
TRADE	0.008 ** [0.00]	0.029 *** [0.01]	0.003 [0.01]	0.014 *** [0.01]
PRICE	0.001 [0.01]	0.183 * [0.10]	0.022 *** [0.01]	−0.573 *** [0.13]
		Indirect effects		
URB	−0.041 [0.48]	−2.397 *** [0.82]	−0.536 [0.48]	−1.227 *** [0.36]
IND	1.092 * [0.56]	−0.151 [1.00]	0.806 [0.68]	0.153 [0.45]
TER	−0.882 * [0.53]	−0.267 [0.95]	−0.704 [0.58]	0.871 [0.62]
PERGDP	−5.221 *** [2.02]	4.382 [5.55]	8.525 [5.83]	−16.921 ** [7.94]
PERGDP2	0.205 ** [0.10]	−0.181 [0.25]	−0.507 [0.32]	0.927 ** [0.45]
FDI	−0.170 ** [0.07]	−0.040 [0.11]	−0.091 * [0.05]	−0.049 [0.04]
TRADE	−0.006 [0.07]	0.137 [0.16]	0.040 [0.08]	0.158 ** [0.07]
PRICE	−0.118 [0.09]	−0.351 [0.24]	−0.209 *** [0.06]	1.208 *** [0.38]
		Total effects		
URB	−0.210 [0.48]	−2.410 *** [0.83]	−0.518 [0.48]	−1.797 *** [0.36]
IND	1.316 ** [0.56]	0.132 [1.00]	0.850 [0.68]	0.318 [0.44]
TER	−0.686 [0.53]	−0.051 [0.96]	−0.606 [0.58]	1.073 * [0.63]
PERGDP	−4.762 ** [2.01]	5.481 [5.58]	8.122 [5.91]	−13.756 * [8.06]
PERGDP2	0.184 * [0.10]	−0.234 [0.25]	−0.482 [0.32]	0.758 * [0.45]
FDI	−0.177 *** [0.07]	−0.054 [0.11]	−0.100 ** [0.05]	−0.052 [0.05]
TRADE	0.003 [0.07]	0.166 [0.16]	0.043 [0.08]	0.172 ** [0.07]
PRICE	−0.117 [0.09]	−0.168 [0.19]	−0.187 *** [0.06]	0.635 * [0.34]

Standard errors are reported in brackets. The superscripts ***, **, and * indicate that the coefficient is statistically significant at the 1%, 5%, and 10% levels.

Significant and negative direct effects of urbanization are reported in the full and the western regions, indicating that a 1% increases of urbanization can directly reduce energy intensity by 0.169% (full region) and 0.570% (western region). However, it fails to find significant direct effects of urbanization in the eastern and central regions [29]. The indirect effects are also significant and negative, except in the central region. It indicates significantly negative spatial spillover effect of urbanization on energy intensity in two of four cases, implying that the countrywide urbanization policy is efficient to constrain energy intensity, especially in the eastern and western regions. The spatial spillover effect is large in the eastern region, thus confirming the tight correlation among cities in the area because of the fast economic development and complete infrastructure construction brought by urbanization. Focusing on the total effect, the significant coefficients for eastern and western regions are −2.410 and −1.797 and they cover the highest and lowest urbanized cities of China, respectively. The key reasons behind the negative effect can be explained in different ways, such as economies of scale, agriculture modernization, economic structural change, urban compaction, consumption preference toward green energy, and application of technological measures for energy conservation [21,22].

Firstly, from the viewpoint of the full sample, only the direct effect is significant and negative. It is noted that a series of strategies to control energy and promote new-type urbanization are carried out in China, such as wind power heating program (National Energy Administration, 2015), construction of a low carbon transportation system (Ministry of Transport, 2014), and standards for energy-saving renovation of public buildings (Ministry of Housing and Rural-Urban Development, 2017). However, the complex relationship between cities induces diversified spillover patterns and the average indirect effect in the full sample conceals the heterogeneity among regions. Secondly, the effect of urbanization in the eastern region, which covers active economic interdependence among cities within the region, is revealed through an indirect effect. Cities in the eastern region are important carriers to attract cross-regional humans and capitals. It benefits from industrial agglomeration [41], concentrated management [56], and economies of scale. In addition, the eastern region has paid more attention to energy shortage and environmental sustainability, as it is more developed with high income and urbanization levels, providing sufficient financial support for the development of advanced energy technology and absorption of technology from surroundings. Thirdly, in the western region, which is not that developed and in the urgent process of transforming from traditional to new-type urbanization, the direct, indirect, and total effects of urbanization on energy intensity are confirmed negative. This negative association points out that increase in urbanization at the early stage (western region) motivates economy of scale, promotes the shift of energy patterns [33], and raises the use of energy-efficient equipment and technology [22,29]. It proclaims that energy intensity can be controlled without affecting urbanization construction of western region. Finally, the inconsistent effects between regions confirm the disparity of urbanization and call for balanced and coordinated construction.

As for the first control variable, industrialization, the direct effect is significantly positive, except in the central region. As a full country, a 1% growth in industrialization can directly boost energy intensity by 0.223% [7], indirectly increase it by 1.092% and totally increase energy intensity by 1.316%. In the eastern region, such growth can bring a 0.283% direct increase, and a 0.151% indirect decrease which is insignificant. The central and western regions reveal positive but insignificant direct, indirect, and total effects, while an exception is the significant positive direct effect in western region. The coefficients of industrialization are positive in the case of direct impact [7,55], whereas they are insignificant in the case of indirect and total effect in three regions. Evidence for indirect and total effects is different from that found by Jiang and Ji [55] and Huang, Du, and Hao [7]. Generally speaking, high industrialization directly leads to the increase of energy intensity in China and the implementation of energy policies during industrialization work. Although economic catch-up is declared by industrialization in the full sample, results for various regions tell a different story. It can be explained by the different economic relationship among cities within regions. For example, the catch-up effect in industrialization occurs across different regions but not within one region.

The 1% growth in the proportion of tertiary industry in the full region, increases energy intensity by 0.196% directly and decreases by 0.882% indirectly. The total effect is a decrease of 0.686%, although such an effect is insignificant. In the eastern region, it directly increases energy intensity by 0.216%, indirectly decreases energy intensity by 0.267%, and the total effect is a decrease of 0.151%. In the central region, it brings an insignificant rise of 0.098% directly and a fall by 0.704% indirectly, the net effect of which is a total sum up to be a fall of 0.606%. At the end, in the western China, the direct, indirect, and total increase are 0.202%, 0.871%, and 1.073%, respectively. The direct effect is significant in all cases, whereas the indirect and total effects are diversified. The significant and positive direct effect is consistent with the finding of Ma and Yu [38], who cover prefectural-city level data from 2005 to 2008 and adopts panel techniques. The positive direct effect may be caused by infrastructure construction with requirement from improved living standard, especially the growing urban population. The development of the tertiary industry is of importance in constraining energy consumption [57] because it is higher value-added and less energy intensive than secondary industry [22]. Although the role of tertiary industry does not work directly, it describes that growing tertiary industry is a cause of energy intensity reduction, which is mostly caused by spatial spillover effect.

In view of GDP, the direct effects display an inverted U-shaped curve [20], with only significant results in eastern and western regions. These effects imply that energy intensity increases when GDP increases at the first stage due to economic development and then falls due to improving technology, and increasing concern for sustainable and environmentally friendly development which is required due to resource efficient and high-quality lifestyle [22].

The direct effect of FDI is insignificant in all regions. It brings negative indirect and total effects in all cases but is only significant in the western region, indicating that FDI may contribute to energy intensity reduction, which is supported by composition and technique spillover effects [38,52]. However, FDI lacks a significant role in reducing energy intensity. An overwhelming majority of FDI flows to the manufacturing and energy intensive industry, which causes a limited technology spillover effect [58]. It presents positive direct effect of international trade, except insignificant result for central region. The indirect and total effects are proven significantly positive only in the western region. Different from the result of Jiang and Ji [55], in this study, international trade is found to be detrimental to energy intensity directly, as China has a large proportion of export, and energy embodied in exported commodities and service is non-negligible part.

Finally, the direct, indirect, and total effects of energy pricing in the total region are insignificant. The direct effect is positive in eastern and central regions but negative in the western region. This result contradicts that of Huang, Du, and Hao [7], in which the analysis is based on provincial data over 2000–2014 and an indicator for relative price. The indirect and total effects in the eastern region are negative and insignificant. The indirect and total effects in central region are significantly negative, which is reasonable and desirable with the target of price regulation [38]. The indirect and total effects in the western region are significantly positive because the primary task in this region is economic development which induces inevitable energy demand. Although marketization of energy pricing has continued for a long time in China, and price reform in the coal market is effective, energy price formation is still heavily dependent on government intervention and is not informative in revealing the market signal of supply and demand [23].

5. Conclusions and Policy Implications

Using a balanced panel data set from 224 prefectural level and above cities in China over the period 2005–2016, this study aims to discover the direct, indirect, and total effects of urbanization on energy intensity. To derive new evidence on the relationship between urbanization and energy intensity at the urban level, we first collect energy intensity and urbanization data in cities from all possible channels. To reveal the direct and indirect effects of urbanization, spatial autocorrelation is subsequently examined and spatial econometric models are established to attain consistent and unbiased results. Finally, the cities are categorized into three regions to reveal the heterogeneous effect of urbanization on energy intensity, producing models for the full sample, and eastern, central, and western regions. The following is the summary of the main conclusions and implications which offer important reference values to urban planners and local governments.

The fairly significant spatial autocorrelation of energy intensity proves the necessity to consider the spatial linkage between cities when making energy consumption and pricing policies. Establishing energy cooperation and communication mechanisms, breaking administrative obstacles, completing infrastructure construction, enhancing spatial linkage, and promoting coordinated development are suggested.

Urbanization seems to be conducive to decreasing energy intensity in the western region through direct, indirect, and total effects [10]. However, urbanization contributes to energy intensity reduction in the eastern region through indirect effects and it does not work significantly in the central region. The insignificant direct effect in the eastern region signals to slow urbanization speed and concentrate on development quality in the eastern region. These findings are consistent with the urbanization and economic development stages of regions in China, in which different energy demands and preferences exist [33]. It is suggested to take regional heterogeneity and characteristics into consideration when making urbanization policies to realize energy saving and environmentally sustainable development [27]. The eastern region of China is located along the coastal line and has a first mover advantage, and is regarded as developed with high urbanization. The eastern region must focus on effective, green, and sustainable development. The central and western regions should strengthen their cooperation with the eastern region and follow in applying advanced energy saving technology and managerial experience from the eastern region. It is important to improve the urban layout and construct energy efficient and environmentally-sustainable urban infrastructure systems, especially in less developed regions [48].

Combined with the positive direct effect of industrialization, upgrading the industrial structure, developing light industry, and transforming the mode of economic growth are recommended because industrialization is an accompanying process of urbanization. Industrial structure adjustment and upgrading helps to redistribute energy among sectors and improve energy efficiency [59]. Policies to resolve excess capacity and eliminate old capacity can help reverse the impact of industrialization.

Based on the undesirable direct effects of tertiary industry, inhibition policy on traditional tertiary industry, policy to develop high value-added technology and knowledge-intensive industries, and funding policies supporting the development and innovation of clean energy are preferred in the tertiary sector. The role of FDI does not work well with regard to direct effects. Thus, implementing effective government policies is recommended to guide the regional and industrial flows of FDI, thereby promoting industry integration and innovation. Improving the absorption ability of technology is effective in utilizing the technology effect of FDI directly [26]. The positive direct effect of international trade appeals to change the growth pattern of trade and optimize the structure of exported products. In addition, the mixed effects of energy price suggest the reduction of price subsidies, relaxation of government intervention, and improvement flexibility of energy price to accelerate the process of factor marketization and make full use of its role as a market signal [23,42].

The present study has certain caveats, which raise new prospects and call for further investigations. Firstly, the sample cities are those with available energy intensity data. Future research may include other cities, and a deep urban level analysis can be conducted for in-depth examination. Secondly, urban population is considered an urbanization process for empirical analysis (due to data availability). Urbanization is a complicated process, and related studies can be extended further to different directions—spatial expansion, economic transmission, etc.—for an in-depth analysis. Thirdly, different results of urban level research from those on a provincial level provide new sights into the local or spatial varying effects of urbanization on energy intensity, which inspires researchers to determine the exact relationship for a given city.

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