Modelling dynamic impacts of urbanization on disaggregated energy consumption in China: a spatial Durbin modeling and decomposition approach

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Abstract Rapid urbanization consumes a variety of energy increasingly. The impacts of urbanization on energy consumption in the past decades have not been investigated by sectors in the literature. Using the time series energy and urbanization related data 1997-2016, we investigate the impacts of urbanization and its interaction with six energy demand sectors on (disaggregated) energy consumption at provincial level in China by integrating the spatial panel data modelling and interaction effects modelling methods. The positive spatial autocorrelation of various energy consumptions justifies the rationale of developing spatial Durbin models. All the diversified direct, indirect and total effects from differently specified models suggest regional and sectoral specific policy to control energy, coal and electricity consumption in the process of urbanization.

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1 Introduction

Since the economic reform and open-door policies in 1978, China has experienced a rapid economic growth (Holz, 2008; Zheng et al., 2009; Perkins, 2012) and unprecedented urbanization process (He et al., 2017), compared with other developing and developed countries in the world (as shown in Fig. 1 and Fig. 2). As an important impetus of national economic growth (Zhao and Wang, 2015), China's urbanization shows a large gap in urbanization level with developed countries, it is reasonable to forecast further increase in its urbanization level and impacts (Chang and Brada, 2006). The Chinese government has made strategic policies to promote urbanization, improve the quality of urbanization, and propose to construct new-type urbanization, which requires human-centered policy making (National New Urbanization Plan, 2014).

The energy consumption has also increased massively especially since 2000 (shown in Fig. 3). China has become the largest energy consumer all over the world from 2009 (British Petroleum, 2011), and which depends on energy import largely (Fig. 4). The energy shortage problem has been increasingly intensified (Yang and Shi, 2017), which is causing great concern on energy security. In addition, energy consumption, in particular the large percentage of fossil fuel, is a main driver of climate change and environment pollution (Guan et al., 2012). Due to remarkable impacts on climate change, peak oil, and energy security, which are accompanied by increasing energy usage, it is imperative for China to control and manage its energy consumption. In the meanwhile, it also needs to fulfill the economic requirement of energy for the production and living consumption in the processes of urbanization and industrialization.

In general, urbanization is a complicated political, socio-economic and spatial process including transformation of production from agriculture to industry and tertiary, and population migration from rural to urban. Population agglomeration in urban areas changes the production pattern, residential lifestyle, and infrastructure demand and transport mode. All these transformations are accompanied by increasing usage of energy, because industry, especially manufacturing industry, is more energy intensive than agriculture. Moreover, the industrial sector of China is extremely energy-intensive (Abdelaziz et al., 2011), and people living in urban areas use more energy than rural areas by deploying more electric appliances etc.(Wei et al., 2007; Dhakal, 2009; Fan et al., 2013), and increasing mobility demand encourages more uses of private transport (Lin and Du, 2015; Yang and Shi, 2017). In addition, government policy on energy conservation (e.g. Thirteenth Five-Year Plan of China, 2015; China energy label, 2016; etc.), public transport improvement, energy conservation lifestyle (e.g. top-leader, etc.) and scale of economy may improve energy efficiency and decrease energy use (Madlener and Sunak, 2011; Wang, 2014), but these mitigation roles maybe canceled out by economic growth and living demand. It is further evident that the rapid urbanization process of China will continue with steady construction of new-type urbanization due to growing employment opportunities, and increasing living standards with high-quality infrastructure, and accessibility in urban areas (Ji and Chen, 2015). Total energy consumption required by economic growth and urbanization will increase continuously (Ji and Chen, 2015). Thus, the following questions are addressed in this study: (1)Does urbanization cause the increase of energy consumption in China? (2) How does it happen in different sectors? (3) What are the determinants on impacts of urbanization on energy consumption? (4) Does the increase of energy consumption in one province have demonstration and spillover effects to its neighbors?

The rest of this paper is organized as follows. Section 2 provides a review on impacts of urbanization on energy consumption in the current literature. Section 3 describes the data and methodology, including the justification of spatial model development. Section 4 presents and discusses modelling results. Section 5 draws the main conclusions, policy implications and limitations of this study.

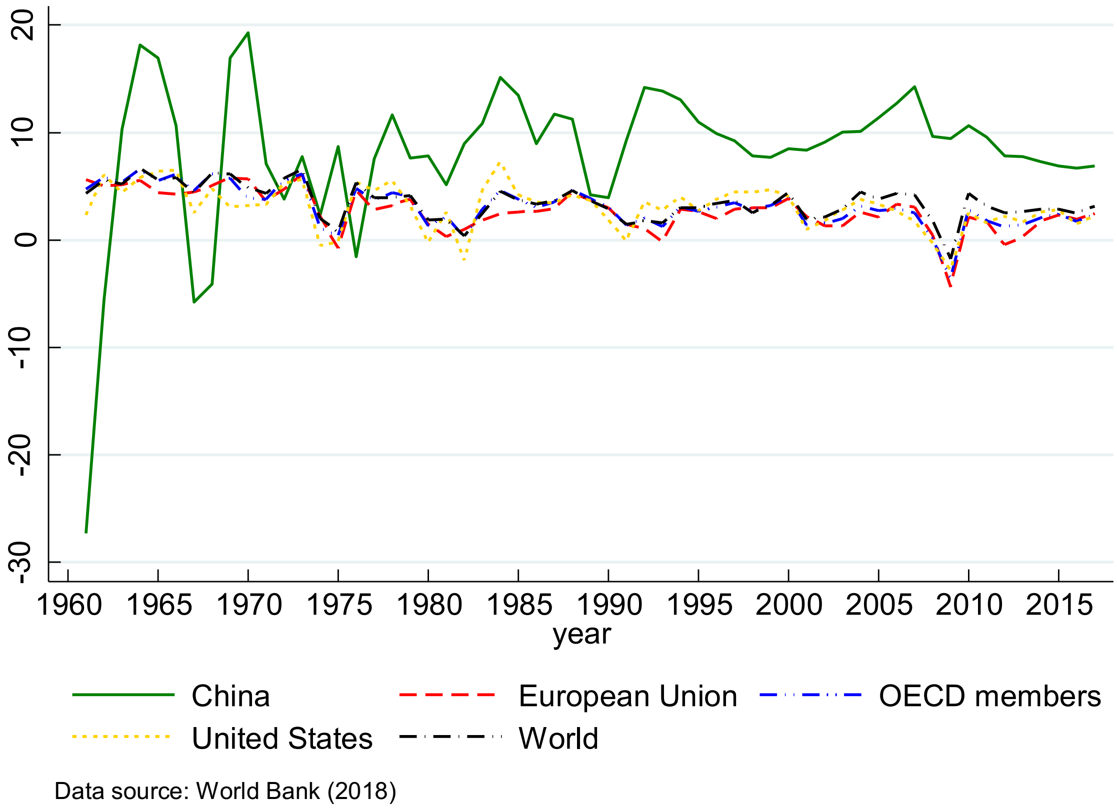

Fig. 1: GDP growth of China, EU, USA, OECD and the world.

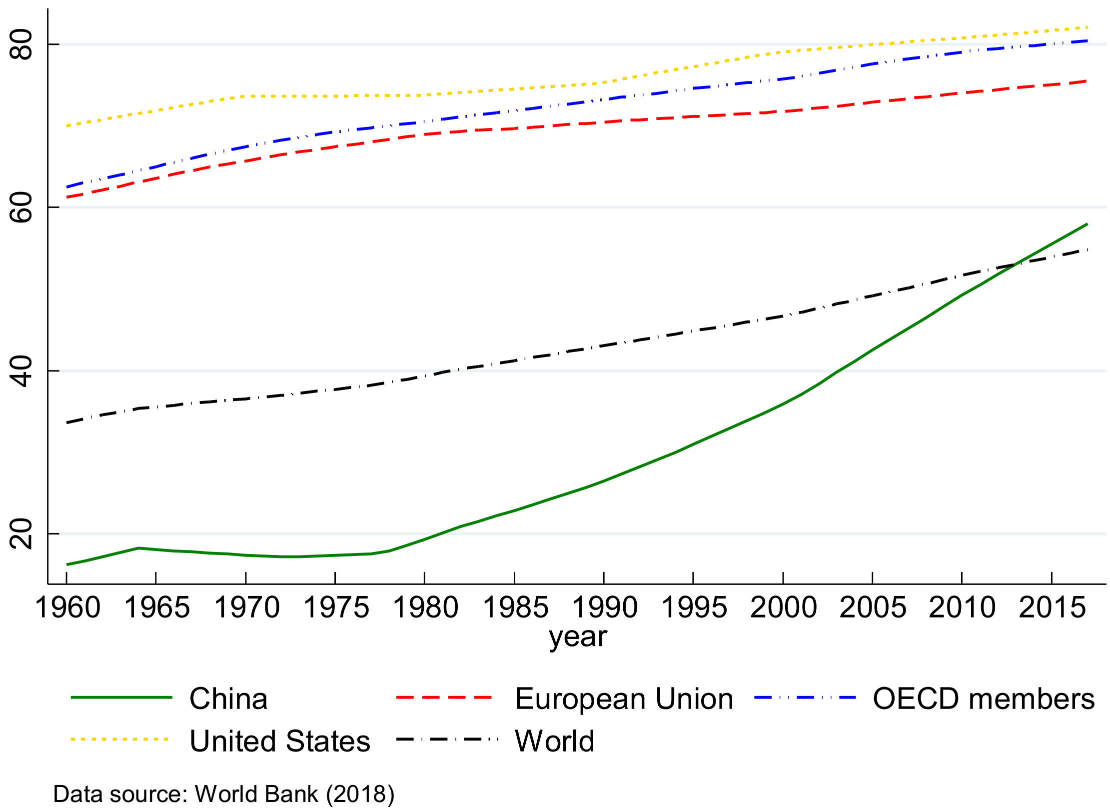

Fig. 2: Urbanization of China, EU, OECD, USA and the world.

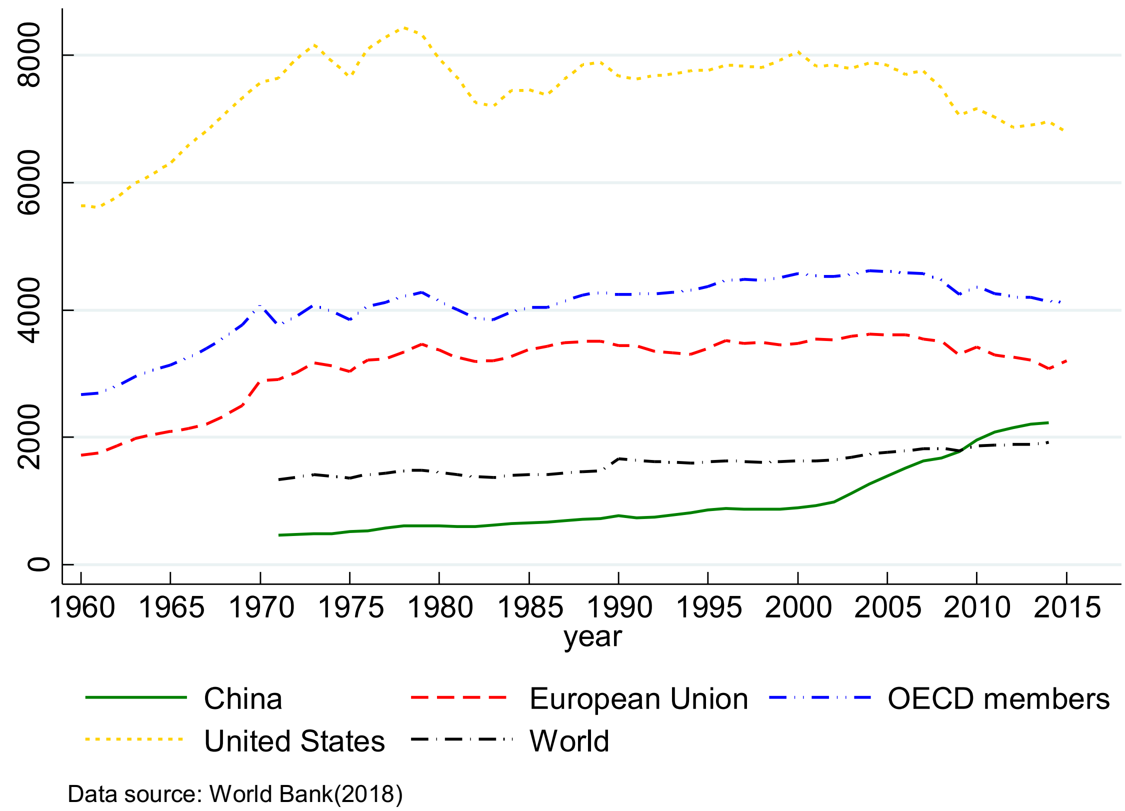

Fig. 3: Energy use of per capita of China, EU, OECD, USA and the world.

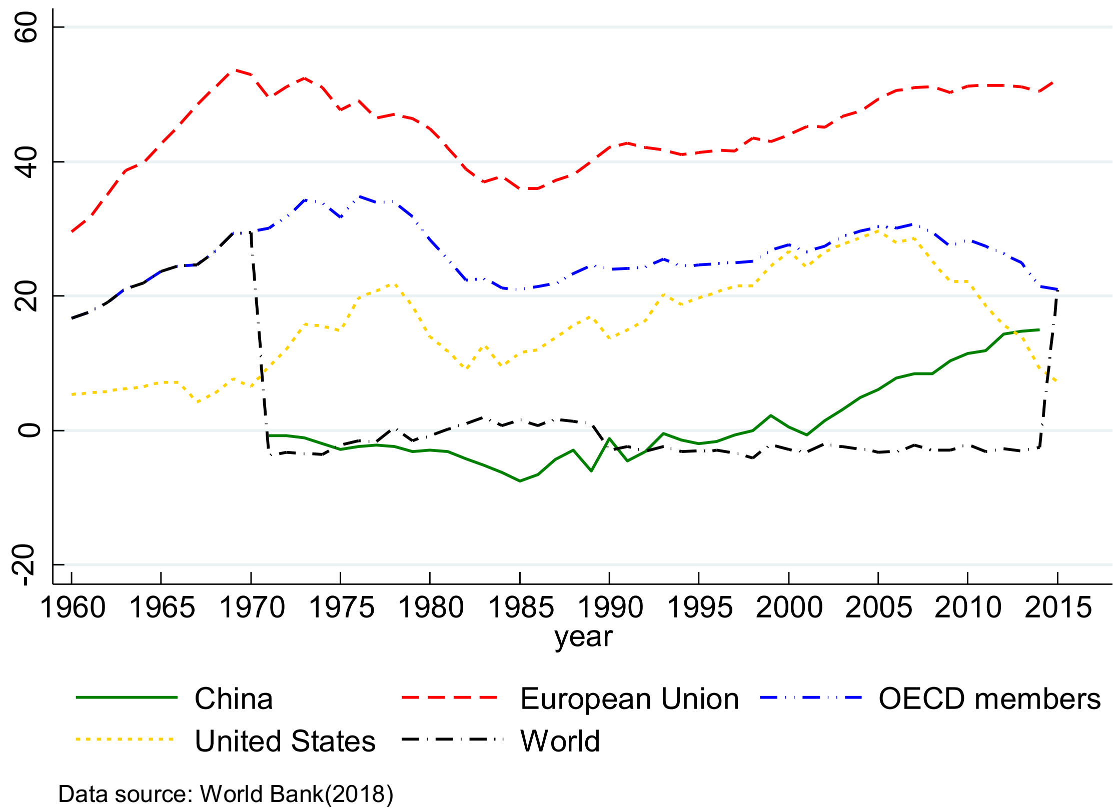

Fig. 4: Energy imports of China, EU, OECD, USA and the world.

2 Literature review

The interdependence between urbanization and energy consumption has been investigated extensively, both in theoretical and empirical frameworks. As an environmental challenge, theoretically, the impact of urbanization on energy consumption is usually discussed within the frameworks of environment theory and urban theory. For example, Jones (1991, 2004) reveals firstly the mechanism on how urbanization process affects energy use. Barnes (2005) details the urban household energy transition for the first time. Ewing and Rong (2008) analyze the casual paths of urban form influences on residential energy use by considering electric transmission and distribution losses, energy requirements of different housing stocks, and space heating and cooling requirements associated with urban heat islands. Poumanyvong and Kaneko (2010) propose three related theories that contribute to explain the relationship: ecological modernization, urban environmental transition, and city compactness. Some recent and most cited work from the perspective of city sectors detailed by Madlener and Sunak (2011) and summarized by Sadorsky (2014a) state the mechanisms to understand the relationships between urban production, mobility and transport, infrastructure and urban density, and private household. Above all, these studies and theories extensively analyze from the perspective of urban form and city sectors, with the behavior of rural area being deleted, but in light of importance of agriculture production in China economy and energy used in agriculture, the agriculture sector is included in this study.

Since the groundbreaking empirical and theoretical work by Jones (1991) and Parikh and Shukla (1995), an emerging ample of empirical literature have focused on modelling the relationship between energy consumption and urbanization, using a wide range of methods from decomposition analysis to some specific econometric analyses. The literature has produced a set of mixed statements regarding the interdependence between urbanization and energy consumption: positive, negative, or unidirectional, bidirectional, and no causality, which might be affected by varied uses of modelling methods and in particular the sampling choice. The time series analysis of Tunisia from 1976 to 2006 by Gam and Rejeb (2012) finds significant short run and insignificant long run impact of urbanization on electricity consumption. Using quarterly data of Malaysia, Shahbaz et al. (2015) validate positive long and short run contributions of urbanization to energy consumption per capita. Some studies state that urbanization level decreases with the increasing energy consumption (e.g. Sadorsky (2014) for emerging economies). In Angola, using time series data from 1971 to 2009, Solarin and Shahbaz (2013) reveal evidence in favor of feedback effects between urbanization and electricity consumption per capita, and the long run positive but short run negative effects. These studies address a noteworthy issue that the effects of urbanization on energy use differ between these specific countries with varied level of income and at different stage of development, not only in the influential magnitude but also influential direction. Many studies try to verify this disparity, by deploying new analytical methods including (1) dividing the sample according income level, and (2) using threshold model or Kuznets curve model. For example, Poumanyvong and Kaneko (2010) find that urbanization reduces energy use in the low-income country group, while it increases energy use in the middle- and high-income country groups. Poumanyvong et al. (2012) report that urbanization affects road transport energy use positively, but the magnitude of coefficient varies between different development-stage and income country groups. The study on 23 Middle East and North African countries by Al-mulali et al. (2013), exhibits positive long run bidirectional relationship between energy use and urbanization, and with larger effect in countries with higher level of income and development. Using threshold models, Li and Lin (2015) split 73 countries into low-income, middle-/low-income, middle-/high-income, and high-income groups, and confirm that its impact on electricity declines as income increases, particularly a significant negative effect is observed in low-income country group, while a positive effect in other three country groups. When investigating the drivers of energy consumption in some developing countries, results from Keho (2016) show that urbanization is a significant determinant of energy consumption per capita in 12 Sub-Saharan African countries, but the direction and magnitude differs a lot between these countries, which also confirms the heterogeneous slope between these countries.

Due to rapid urbanization, high-level energy consumption and large-scale carbon emissions in China, the studies on the impacts of urbanization on energy consumption in China have attracted much attention recently (Wang et al., 2014; Liu et al., 2016). Using the statistical data of China from 1978 to 2008, Liu (2009) reports a unidirectional impact of urbanization on total energy consumption both in the long run and in the short run, with ARDL bounding test and factor decomposition model. Zhou and Zang (2011) confirm that the impact of urbanization on energy consumption demonstrates scale and technical effects using time series data of China from 1978 to 2008, and the energy saving effect of tertiary is not obvious. Michieka and Fletcher (2012) report significant unidirectional causality from urbanization to electricity production in the period 1971-2009, but no relationship between coal consumption and urbanization is found. Zhang and Lin (2012) has provided the evidence of significantly positive impact of urbanization on energy consumption by using provincial panel data from 1995 to 2010 in China and considering the unobserved heterogeneity among regions into a region division method. However, these results vary with regions and panel estimation methods. Wang (2014) finds and distinguishes the different effects of urbanization on residential energy consumption (REC) and production energy consumption (PEC) in China by using time series data from 1980 to 2011 and a decomposition analysis method. Using a provincial panel data set over the period 1995-2011, Wang et al. (2014) produce evidence of bidirectional relationship between per capita energy consumption and urbanization in China, and prove spatial heterogeneity present at the provincical level, which is caused by economic scale. Zhou et al. (2015) investigate four indicators of rural-urban development transformation, and reveal significant positive impact of urbanization on energy consumption at province level, but which has spatial variation between three regions. Using a three-step methodology to identify the influence mechanism of urbanization on energy consumption in China, Shao and Chen (2015) identify the positive impacts of economic scale, urban population, income and Engel's coefficient on energy consumption but negative impacts from proportion of secondary industry during urbanization. By concentrating on the household energy consumption in China from 1997 to 2013, Ding et al. (2016) reveal its spatial heterogeneous effects by dividing the whole sample into north-south and west-east, and conclude that urbanization level has more significant impact on the structure and efficiency of household energy consumption than on its quantity. In contrast to positive impacts highlighted in the most above-mentioned results, Liu et al. (2017) model the impact of urbanization on energy consumption across China using a spatial panel model method, and conclude demonstration effects in inter-regional energy consumption. There have been no significant negative impact of urbanization on energy consumption from the study.

The increasing urbanization pressures driven by the large-scale urban transformation have complicated such impacts on energy consumption. The empirical study results in the published literature are not coherent in terms of the utilized samples or modelling methods. First, there have been rare studies on the empirical analysis about how urbanization affects energy consumption through these mechanisms (Shao and Chen, 2015) or how to identify the diversified work of these mechanisms empirically. Tracking the exact mechanisms, through which urbanization affect energy consumption, is meaningful for exploring the sector and region specific relationship and then make sector and region specific policy. Secondly, a majority of Chinese case studies have not considered the spatial autocorrelation in energy consumption and urbanization into the model development. A balanced urbanization process in such a large-area country is highly determined by the complicated socio-economic interactions or inter-dependence between these provinces and regions, which may share common opportunities, challenges and constraints. Some of these processes may exhibit remarkable demonstration effect spatially and temporally, which means a successful project or good policy practice will have massive influences on neighouring provinces or regions immediately or in a short period. Some studies have applied panel data modelling method to deal with cross sectional dependence (Liddle and Lung, 2013; oban and Topcu, 2013), but seldom dealt with spatial dependence present in the data set (Liu et al., 2017). Thirdly, the socio-economic processes driving urbanization might be not homogeneous across the country as the central government has regulated temporally varied national development strategies and policies, e.g. from the Shenzhen Special Zone, to coastal cities, Shanghai, the central part and now to the development of western region (National People's Congress, 2000), to a coordinated regional development strategy (the Communist Party of China in the third Plenary Session of the 16th CPC Central Committee, 2003). The spatial imbalance in development strategies has led to imbalanced economic development, or called regional inequality, including increasing income gaps, which result in different energy usage strategies and policies. Thereby, there might be spatially varying relationships between urbanization and energy consumption as well all as their determinants between provinces, which requires specific regional policy making respectively. This kind of spatial heterogeneity or nonstationary can be handled by integrating spatial specific effects into spatial models, which is calling for spatial econometrics. Fourthly, when calculating energy consumption, some conversion factors are used to aggregate different types of energy based on the assumption of homogeneous and substitutable distributions. However, this assumption is often violated in reality. As such, this paper investigates the aggregated energy as well as disaggregated ones including coal and electricity consumption (Wu et al., 2017). The disaggregation of energy consumption for spatial modelling enables to detect not only spatial but also (energy) structural heterogeneity and accordingly helps better understand the complicated impacts. All these proposed development will fill in the literature gaps in modelling the impacts of urbanization on energy consumptions.

Summing up, the contributions in this paper can be three folds. First, the spatial fixed effects will be specified and considered to control the spatial heterogeneity at province level. Second, using energy consumption data from 6 sectors, the interaction effects models will be combined with spatial models to investigate the influential mechanisms through which urbanization affects energy consumption. An accompanied contribution of adding the interaction is to investigate the heterogeneous effects of urbanization on energy consumption under different urbanization level and sectoral consumption level. Although there have been many researches on the impact of urbanization on energy, few focus on the impact mechanism from different sectors. Third, the disaggregation of energy consumption into coal and electricity categories enables the identification of specific impacts on different type of energy and attains a more reliable and detailed result.

3 Methods and data

3.1 Modelling Methods

All the regions across China have diversified energy demand but they are spatially dependent with each other due to corresponding socio-economic dependence. First, the production factors (material goods, energy and labors) spreads nationwide. The goods and services are consumed nationwide, especially pushed by the improvement of transportation system. Second, the lifestyle and preference of electric appliance between neighbors are similar because of similar weather conditions, resource endowment and economic development. Third, long distance commuting and alien consumption, resulting from the spatial interaction (or separation) between residence and workplace, induce the spatial dependence of energy consumption between adjacent regions in the process of urbanization. Finally, the economic policies in China are always nationwide and region-specific. Considering the spatial dependence in energy consumption at province level, it is reasonable to establish spatial models for research.

First, before developing a spatial model, both the global and local Moran's I index (Anselin, 1995) are chosen to examine whether there is spatial autocorrelation in any energy related variable.

The global Moran's I index is defined as:

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

Where x_i is energy, coal, or electricity consumption in region i; w_{ij} measures the inverse economic distance between provinces i and j, which is the element of spatial weight matrix and is constructed in the following step. All w_{ij} form a spatial weight matrix; and $S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}$. When $I > 0$, it indicates positive spatial autocorrelated, which means the high (low) value is surrounded by high (low) value. When $I < 0$, it indicates negative spatial autocorrelated, which means the high (low) value surrounded by low (high) value. Spatial autocorrelation is a form of spatial dependence, which is the first law of geography (Tobler, 1970): the near things are more related than distant things. Positive autocorrelation reflects a global clustering pattern and the negative one for a dispersed pattern.

Then, local Moran's I_i is used to detect the spatial clusters of any variable across the study area:

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

This local Moran's I_i can be shown intuitively by a Moran scatter plot, in which the horizontal axis (z) represents the standardized values of the variable and the vertical axis (Wz) represents the spatial lag of the standardized values (Anselin, 1995). In the Moran scatter plot, the global Moran index can be visualized as the slope of a linear regression of Wz on z.

Second, if the spatial autocorrelation in the first step is confirmed and proved, then a spatial model should be necessarily developed for exploring the impact of urbanization on energy consumption across the study area. Many literature have added urbanization as a core variable into the STIRPAT model (Sadorsky, 2014; Zhou et al., 2015; Ding et al., 2016). Based on the STIRPAT model and following the strategy of general to specific approach (Mur and Angulo, 2009), modelling can start with spatial Durbin model (SDM, which is defined by Anselin, 1988) as a general specification and test for seeking alternatives. The following spatial Durbin model is specified for this purpose:

$$\begin{aligned}
& consumption_{it} \\
= \; & \rho \sum_{j=1}^{N} w_{ij} consumption_{jt} + \beta_1 urbanization_{it} + \beta_2 GDP_{it} + \beta_3 industrilization_{it} \\
& + \beta_4 tertiary_{it} + \beta_5 population_{it} + \beta_6 FDI_{it} + \beta_7 trade_{it} + \beta_8 eprice_{it} + \beta_9 estructure_{it} \\
& + \theta_1 \sum_{j=1}^{N} w_{ij} urbanization_{jt} + \theta_2 \sum_{j=1}^{N} w_{ij} GDP_{jt} + \theta_3 \sum_{j=1}^{N} w_{ij} industrilization_{jt} \\
& + \theta_4 \sum_{j=1}^{N} w_{ij} tertiary_{jt} + \theta_5 \sum_{j=1}^{N} w_{ij} population_{jt} + \theta_6 \sum_{j=1}^{N} w_{ij} FDI_{jt} + \theta_7 \sum_{j=1}^{N} w_{ij} trade_{jt} \\
& + \theta_8 \sum_{j=1}^{N} w_{ij} eprice_{jt} + \theta_9 \sum_{j=1}^{N} w_{ij} estructure_{jt} + \mu_i + \varepsilon_{it} \qquad (3)
\end{aligned}$$

where $consumption_{it}$ represents total energy, coal, or electricity consumption respectively, μ_i is the specific effects, and ε_{it} is the error term. The variables of *urbanization*, *GDP*, *industrialization*, *tertiary*, *population*, *FDI*, *trade*, *eprice*, and *estructure* respond to urbanization, Gross Regional Production, percentage of industry value added in GDP, percentage of tertiary value added in GDP, population size, Foreign Direct Investment, trade, energy price and energy structure respectively. In addition, following the STIRPAT model, all variables are taken natural logarithms, which also helps to avoid heteroscedasticity and alleviate order of magnitude. The coefficients ρ and θ measure the spatial spillover effect of dependent and independent variables, for example, in the model for coal consumption, ρ represents the average percentage change of coal in one region when the coal in surrounding regions changes 1%.

This is a general spatial panel model, and can be simplified. If $\theta = 0$, the spatial Durbin model will be simplified to spatial lag model. If $\theta + \delta\beta = 0$, the spatial Durbin model will be simplified to spatial error model. So Wald tests and likelihood ratio tests, for the two kinds of null hypothesizes: $\theta = 0$ and $\theta + \delta\beta = 0$, will be performed respectively.

To explore the moderate effects between urbanization and sectoral energy demand, the panel models with interaction effects are specified by adding the energy demand of the specific sector and its interaction term with urbanization into the above-mentioned model (equation 3). For example, to investigate the moderate effect of urbanization and construction sector demand on coal consumption, the interaction model is specified as:

$$
\begin{aligned}
coal_{it} = {} & \rho \sum_{j=1}^{N} w_{ij} coal_{jt} + \beta_1 urbanization_{it} + \beta_2 GDP_{it} + \beta_3 industrilization_{it} \\
& + \beta_4 tertiary_{it} + \beta_5 population_{it} + \beta_6 FDI_{it} + \beta_7 trade_{it} + \beta_8 eprice_{it} + \beta_9 estructure_{it} \\
& + \theta_1 \sum_{j=1}^{N} w_{ij} urbanization_{jt} + \theta_2 \sum_{j=1}^{N} w_{ij} GDP_{jt} + \theta_3 \sum_{j=1}^{N} w_{ij} industrilization_{jt} \\
& + \theta_4 \sum_{j=1}^{N} w_{ij} tertiary_{jt} + \theta_5 \sum_{j=1}^{N} w_{ij} population_{jt} + \theta_6 \sum_{j=1}^{N} w_{ij} FDI_{jt} \\
& + \theta_7 \sum_{j=1}^{N} w_{ij} trade_{jt} + \theta_8 \sum_{j=1}^{N} w_{ij} eprice_{jt} + \theta_9 \sum_{j=1}^{N} w_{ij} estructure_{jt} \\
& + \beta_{10} concoal_{it} + \beta_{11} concoal_{it} * urbanization_{it} \\
& + \theta_{10} \sum_{j=1}^{N} w_{ij} concoal_{jt} + \theta_{11} \sum_{j=1}^{N} w_{ij} concoal_{jt} * urbanization + \mu_i + \varepsilon_{it}. \qquad (4)
\end{aligned}
$$

The spatial models (3) and (4) are extended from the following panel models.

$$
\begin{aligned}
consumption_{it} = {} & \alpha + \beta_1 urbanization_{it} + \beta_2 GDP_{it} + \beta_3 industrilization_{it} + \beta_4 tertiary_{it} \\
& + \beta_5 population_{it} + \beta_6 FDI_{it} + \beta_7 trade_{it} \qquad (5) \\
& + \beta_8 eprice_{it} + \beta_9 estructure_{it} + \mu_i + \varepsilon_{it}
\end{aligned}
$$

$$
\begin{aligned}
coal_{it} = {} & \alpha + \beta_1 urbanization_{it} + \beta_2 GDP_{it} + \beta_3 industrilization_{it} + \beta_4 tertiary_{it} \\
& + \beta_5 population_{it} + \beta_6 FDI_{it} + \beta_7 trade_{it} + + \beta_8 eprice_{it} + \beta_9 estructure_{it} \qquad (6) \\
+ \quad & \beta_{10} concoal_{it} + \beta_{11} concoal_{it} * urbanization_{it} + \mu_i + \varepsilon_{it}
\end{aligned}
$$

In an ordinary regression model, the coefficient β_1, which is partial derivative of the coal with respect to urbanization, reflects the local impact of urbanization on coal consumption.

The impact of local urbanization on local coal consumption in ordinary interaction effects model (6) is $\beta_1 + \beta_{10} concoal$. However, in the case of spatial model, they are only partial effects. The coefficient of a independent variable represents the local effect and the coefficient of a spatial lagged independent variable is spatial spillover effect, but it may be biased because of feedback loop effect. For example, a change (increase or decrease) of urbanization level in a specific province may have influences on the coal consumption in all other provinces since further development of urbanization in the specific province demands and imports massive energy not only from the province itself but also from other provinces, which enhances the impact of urbanization due to spatial dependent coal consumption. Such spatial effect has been expressed in the spatial lag terms. Consequently, as Lesage and Pace (2009) propose to measure and distinguish spatial effects of independent variables, it is imperative to consider the direct, indirect and total effects of spatial Durbin model. To derive these effects, the spatial Durbin model is rewritten as follows:

$$y = (I_n - \rho W)^{-1} X\beta + (I_n - \rho W)^{-1} W X\theta + (I_n - \rho W)^{-1} \tau_n \alpha + (I_n - \rho W)^{-1} \varepsilon \tag{7}$$

Denoting

$$\begin{aligned} X\beta &= (x_1, x_2, \cdots, x_k)(\beta_1, \beta_2, \cdots, \beta_k)' = \textstyle\sum_{i=1}^{k} x_i \beta_i \\ X\theta &= (x_1, x_2, \cdots, x_k)(\theta_1, \theta_2, \cdots, \theta_k)' = \textstyle\sum_{i=1}^{k} x_i \theta_i \end{aligned} \tag{8}$$

$$\begin{aligned} V(W) &= (I_n - \rho W)^{-1} = I_n + \rho W + \rho^2 W^2 + \cdots \\ S_r(W) &= V(W)(I_n \beta_r + W\theta_r) \end{aligned} \tag{9}$$

Then

$$
\begin{aligned}
y &= V(W)X\beta + V(W)WX\theta + V(W)\tau_n\alpha + V(W)\varepsilon \\
&= \textstyle\sum_{r=1}^{k} S_r(W)x_r + V(W)\tau_n\alpha + V(W)\varepsilon
\end{aligned} \tag{10}
$$

Thus, the partial derivative of dependent variable y with respect to the r-th exogenous variable in X is denoted as follows:

$$
\frac{dy}{dx_r} = S_r(W) = (I_n - \rho W)^{-1}(I_n\beta_r + W\theta_r) \tag{11}
$$

The partial derivative of dependent variable y at location i with respect to the r-th exogenous variable at location j is represented as follows:

$$
\frac{dy_i}{dx_{jr}} = (S_r(W))_{ij} = ((I_n - \rho W)^{-1}(I_n\beta_r + W\theta_r))_{ij} \tag{12}
$$

When $j = i$, it represents own derivative for the i-th region, the change of y (in region i) in response to local change in independent variable x (in region i). When $j \neq i$, it indicates the change of dependent variable y in response to independent variable change of its neighbors. This is obviously not equal to the coefficient of model. Thereby, for a given independent variable, its impact on dependent variable depends on location or observation. Lesage and Pace (2009) define the average effects in all locations as direct effects that represent the average impact of local independent variable on local dependent variable, the average total impact from an observation as the total effects, and the average indirect effect (or spatial spillover effect) is defined as difference between total and direct effects.

$$
direct_r = \frac{\sum_{i=1}^{n} S_r(W)_{ii}}{n} = \frac{tr(S_r(W))}{n} \tag{13}
$$

$$
total_r = \frac{\tau_n' S_r(W)\tau_n}{n}, \quad indirect_r = total_r - direct_r \tag{14}
$$

Third, the measurement of inverse economic distance between spatial units, the province in this case, is a key step to the construction of spatial weight matrix, which is of great importance for spatial econometric model and will be used in both the first and second procedures above. According to Lin et al. (2005, 2006), only the weight matrix defined by geographical distance cannot reveal the economic interactions between Chinese provinces. So it is proposed to construct a spatio-economic weight matrix by measuring both the geographical and economic distances (e.g. Liu et al.,2017). Fingleton and Gallo (2008) also emphasize that the spatial spillover depends on not only spatial proximity but also economic distance. The spatio-economic weight matrix in this study is constructed following the work by Lin et al. (2005, 2006).

3.2 Data

Considering data consistency and availability, a balanced panel data set of 30 provinces in China from 1997 to 2016 is created in this paper. The original data are collected from the China Statistical Yearbook, the China Energy Statistical Yearbook, and the Regional Statistical Yearbooks (1998-2017). Due to data unavailability, those regions including Tibet (Xizang), Hong Kong, Macau, and Taiwan are excluded from this case study. Missing data of Ningxia from 2000 to 2002 and Hainan in 2002 are amended by linear interpolation.

The dependent variables of energy consumption include total energy, coal, and electricity consumption, which are all transformed into standard coal equivalent value by the conversion factors from physical unit to coal equivalent published in China Energy Statistical Yearbook (2017). The core independent variable for this study is urbanization level, which is defined as percentage of urban population over its total population, and the data before 2000 was amended by Zhou and Tian (2006).

Eight independent variables, which are mostly investigated in previous studies, are chosen as control variable, including GDP, FDI, trade, industrialization, population and proportion of tertiary industry value added to GDP, energy price and energy structure. In order to avoid the effect of inflation, data is adjusted to the constant price of the base period 1997. Gross Regional Production has been extensively studied in energy consumption (Coers and Sanders, 2013; Adom, 2015). Energy is the necessary factor for production. It is expected that GDP has profound impact on energy consumption. Ozturk (2010) and Payne(2010) have reviewed the relationship between energy and growth, and summarize the relationship into four types: no causality (neutrality hypothesis), uni-directional causality running from economic growth to energy consumption (conservation hypothesis), uni-directional causality running from energy consumption to economic growth (growth hypothesis) and bidirectional causality (feedback hypothesis). Industrialization is the main impetus of economic development in China, and secondary industry, especially the manufacturing industry is energy intensive. Thereby, industrialization tends to promote energy consumption (Sadorsky, 2014; Li and Lin, 2015). Population size is a demographic indicator. The energy evolution is indispensable to urbanization and the growth of population, and the increasing population urges clean energy substitution for fossil fuel (Liu, 2009; Liddle, 2014). Tertiary is less energy intensive compared with industry. Due to urbanization and the improving standard of residents, there is great space for the development of service industry. The contribution of tertiary value added to GDP is growing in China. The effect of tertiary on energy causes much concern (Wang, 2012; Liu et al., 2017). FDI and trade are considered as way of technology transfer. Although widely discussed (Sbia et al., 2014; Nasreen and Anwar, 2014; Shahbaz et al., 2015; Keho, 2016), the impacts of FDI and trade on energy consumption are ambiguous and inconsistent. Trade openness and FDI affect energy consumption through scale effect, and technique effect (Hbler and Keller, 2010). According to economic theory, energy price is an indicator of market signal which is determined by supply and demand in a perfectly competitive market. Theoretically, energy demand decreases when energy price increases (Jiang and Lin, 2012; Liu et al., 2017). Although there are three energy variables being valued in this study, the purchasing price indices for fuels and power is chosen as a common indicator to control the effect of energy price (Lin and Chen, 2018). Energy structure represents the composition of energy types in energy consumption. Energy substitution towarding clean energy helps to alleviate energy shortage and climate change. The optimization of energy structure does not mean a blindly reduction of coal and the equilibrium state of energy tends to be a stable balance between energy forms. So, the energy structure indicator based on information entropy method is adopted in this study (Geng et al., 2004; Tian et al., 2009).

According to the theoretical analysis by Madlener and Sunak (2011), there are mainly four sectors in which urbanization changes and moderates their energy demand behavior, and the four sectors are composed of urban production, construction, transportation, and residential living. Besides, industrial system and structure are heterogeneous among Chinese regions due to resource and factor endowment, which implies unequal energy use and composition among sectors and regions. The urbanization process is inseparable with the industrial adjustment process which indicates an interaction effect on energy between urbanization and industrial sectors. Combined with the statistical data of Energy Balance Table by Region published in China Energy Statistical Yearbook(1998-2017), the following six sectors have been focused for data collection: (1) Agriculture, Forestry, Animal Husbandry, Fishery (for short, agriculture), (2) industry, (3) Construction, (4) Transport, Storage and Post (for short, transport), (5) Wholesale, Retail Trade and Hotel, Restaurants (for short, retail), (6) Residential Consumption (for short, residential), are chosen here. The agriculture is considered as primary industry (for short, agriculture). The industry and construction can be considered as secondary industry. All the data for energy, coal, and electricity demand in these sectors are collected from China Energy Statistical Yearbooks (1998-2017), and are transformed into standard coal equivalent value (104 tce) by the conversion factors from physical unit to coal equivalent published in China Energy Statistical Yearbook. The summary statistics of these variables for 30 provinces of China in the sample period 1997-2016 are presented in Table A1.

The Industrial classification for national economic activities in China has been modified in 2011, and the energy data of 2012 has followed the new standard of classification. This has been reflected in the China Energy Statistical Yearbook (2013), in which the data items for industry sector have been adjusted. The other five sectors (agriculture, etc) remain same. So, the sub-sectors in industry sector are adjusted as follows. First, the item "support activities for mining" is added as a new group under division of "mining and quarrying". The national percentage of energy (coal, electricity) consumption in "support activities for mining" to its national total industry consumption is used to adjust the values of these relevant data after 2012 at province level. Second, other modifications include the replacement of "manufacture of beverages", "manufacture of activities for culture, education and sport activity" by "manufacturing of liquor, beverages and refined tea", and "manufacture of activities for culture, education, arts and crafts, sport and entertainment activities" respectively. Third, although the item "manufacture of transport equipment" is divided into two items "manufacture of automobiles" and "manufacture of railway, ship, aerospace and other transport equipment", they still belong to the industry sector, so it does not need to adjust these data. Fourth, the item "repair service of mental products, machinery and equipment" is added as a new sector after 2012, so its data are adjusted using the same method of "support activities for mining" sector mentioned above .

4 Results

4.1 Spatial autocorrelation of energy consumptions

As shown in Table 1, the spatial autocorrelation calculated by Moran's I, exhibits significant positive values, particularly in the recent years, apart from insignificant values in some years before 2001. This implies that energy, coal, and electricity consumptions demonstrate spatial clustering pattern from agglomeration effects as those provinces with high (or low) consumption values are clustered.To explore the spatial effects in specific provinces, the scatter plots of local Moran's I_i are drawn for total energy consumption (Fig. 5), coal (Fig. 6) and electricity (Fig. 7) in 2016. In these figures, the z-axis represents the standardized values of local energy (coal, electricity) and the Wz-axis their spatial lags. Taking 2016 as an example, as shown in Fig. 5, most provinces are located in the lower left and upper right quadrants, in accordance with the spatial cluster effects detected by global Moran's . Conversely, those provinces including Sichuan, Xinjiang, Guangdong, and Chongqing, in the upper left and lower right quadrants, have dissimilar values of energy consumption in its region which means lower values are surrounded by high values and vise verse, but it should be noted that these provinces are located close to the boundary between the lower left and upper right quadrants. The distributions of total energy consumption, coal and electricity consumption show a similar spatial pattern at province level. The spatial effects, spatial dependence in this case, as illustrated above, require a strict consideration into modelling the impacts of urbanization on energy consumptions.

Table 1: Global Moran I values of energy, coal, and electricity consumption.

	Moran's I				Moran's I		
year	energy	coal	electricity	year	energy	coal	electricity
1997	0.175	0.286**	0.139	2007	0.294**	0.388***	0.246*
1998	0.181	0.305**	0.128	2008	0.297**	0.394***	0.236*
1999	0.200	0.321**	0.129	2009	0.299**	0.382**	0.225*
2000	0.203	0.316**	0.122	2010	0.299**	0.364**	0.229*
2001	0.218	0.353**	0.117	2011	0.299**	0.366**	0.233*
2002	0.251*	0.397**	0.123	2012	0.281*	0.334**	0.226*
2003	0.251*	0.379**	0.129	2013	0.257*	0.331**	0.219*
2004	0.261**	0.382**	0.159	2014	0.249*	0.319**	0.206*
2005	0.276**	0.385***	0.185*	2015	0.247*	0.334**	0.186
2006	0.283**	0.381***	0.216*	2016	0.243*	0.332**	0.188*

Note: $^{*}p < 0.05,^{**} p < 0.01,^{***} p < 0.001$.

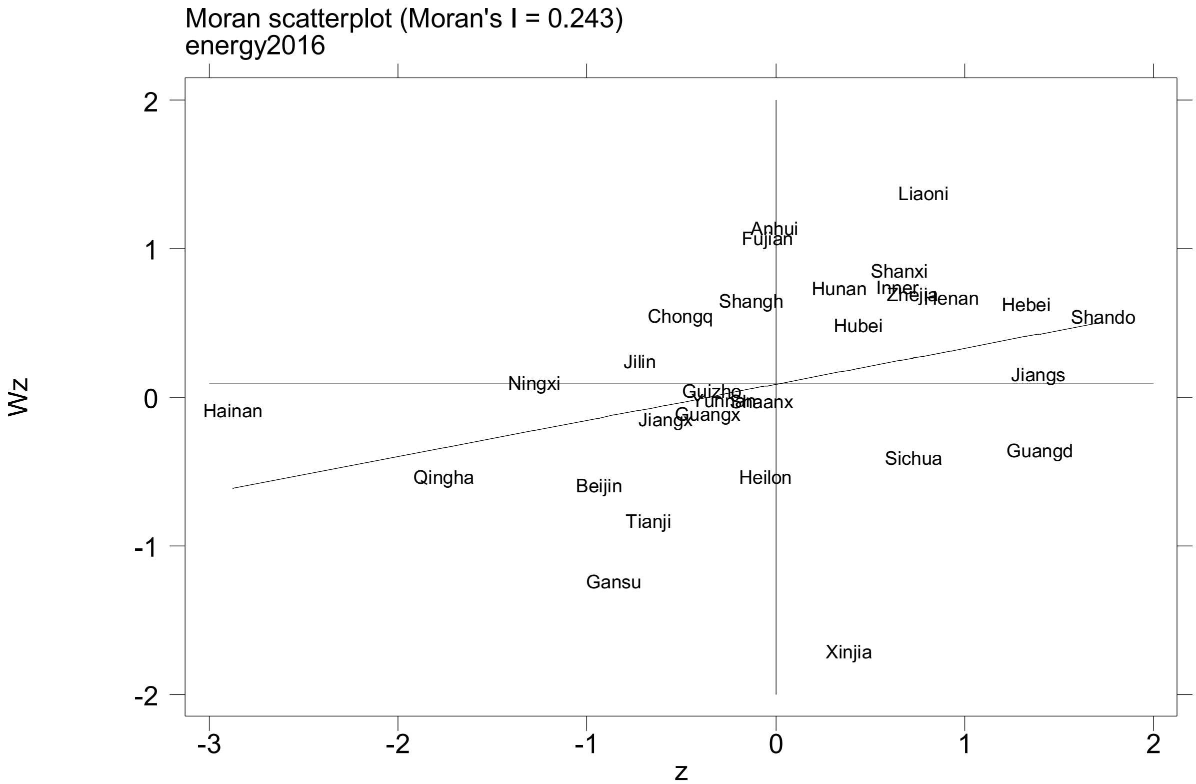

Fig. 5: Local Moran's I values for energy consumption at provincial level (year 2016).

4.2 Spatial modelling results

The estimated results from panel and spatial models for energy, coal, electricity consumption are listed in Tables 2, 3, and 4, respectively. In all the tables, column (1) lists the results from panel model, column (2) from spatial Durbin model without interaction effects considered, and the remaining columns (3) to (8) from the spatial Durbin model with interaction effects of agriculture, industry, construction, transportation, retail and residential sectors, respectively. The panel and spatial panel models are developed to examine whether urbanization is a significant determinant for energy, coal and electricity consumptions. The results shown in columns (1)-(2) of Tables 2-4 reveal that urbanization affects energy, coal and electricity consumptions significantly and positively. Following up, the interaction effects model is developed to explore the influential mechanism of urbanization on energy consumption. The model results in the three tables are split into three parts: socio-economic independent

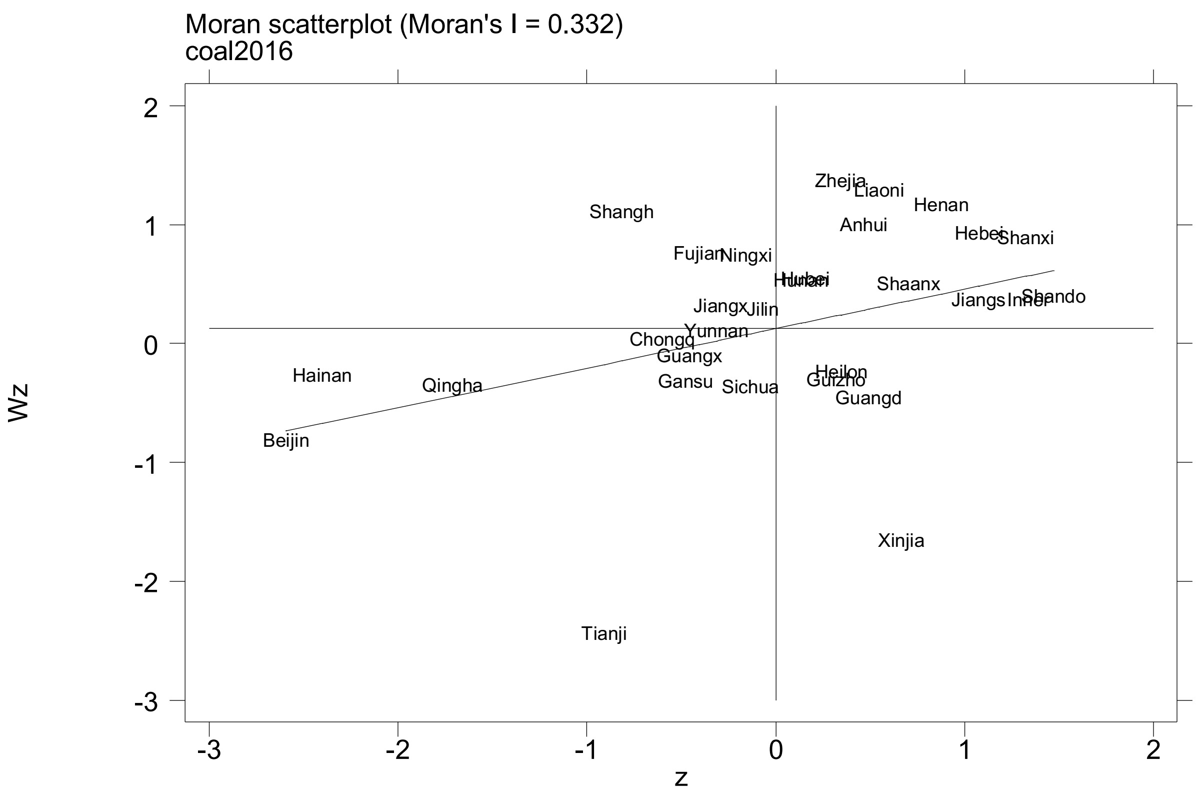

Fig. 6: Local Moran's I values for coal consumption at provincial level (year 2016).

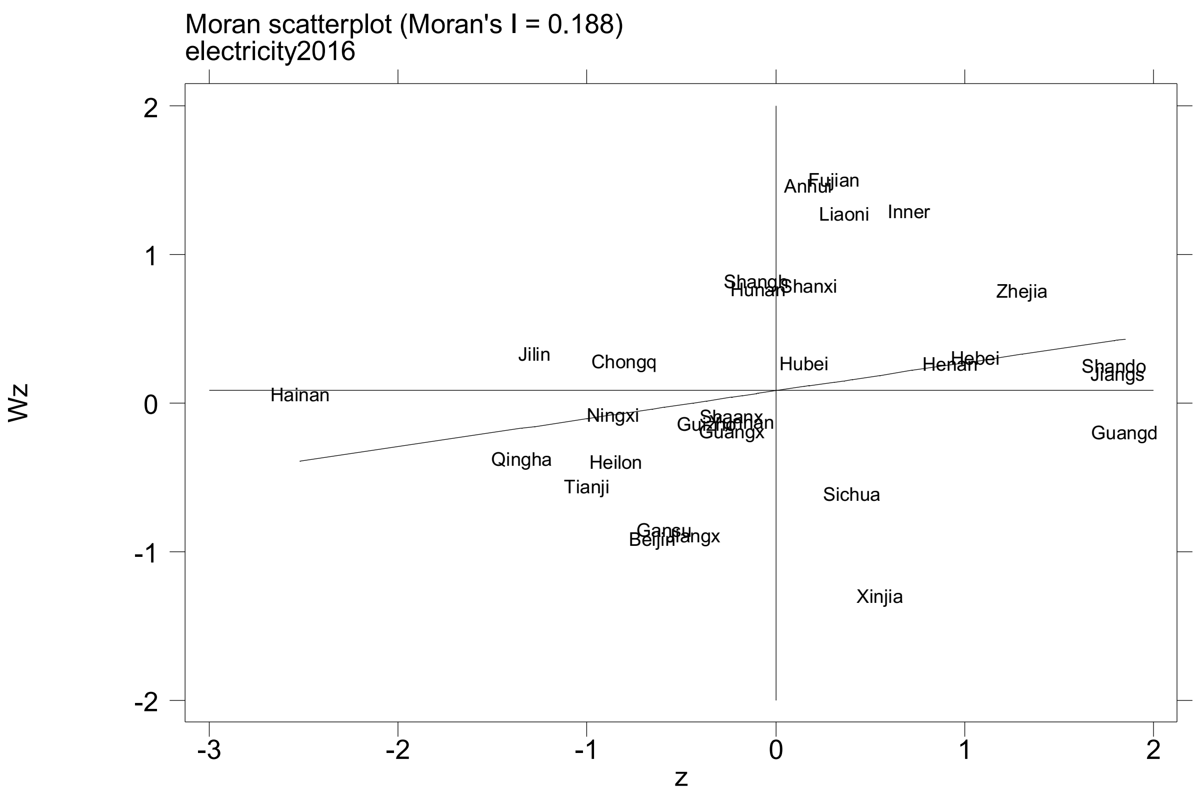

Fig. 7: Local Moran's I values for electricity consumption at provincial level (year 2016).

variables (e.g. GDP), spatially lagged dependent (e.g. W*energy) and independent variables (e.g. W*GDP), and diagnostic tests for model simplification and specification. According to general to specific rule of developing a spatial panel model, a spatial Durbin model is constructed as a starting point after the confirmation of spatial autocorrelation, and the Wald test and log likelihood ratio test for spatial lag and error are used to verify whether the spatial Durbin model should be simplified to spatial lag or spatial error model. Taking the model of total energy consumption in Table 2 as an example, the Wald test and log likelihood ratio test for spatial lag or spatial error are all rejected at the significant level of 1%. This indicates that the spatial Durbin model should be developed to quantify the relationships between urbanization, GDP, FDI, trade, industrialization tertiary, population, energy price, energy structure and energy consumption. In addition, the Hausman test for the null of random spatial specific effects suggest that spatial models with fixed spatial specific effects should be chosen in columns (3) (6) (7) and (8) at the significant level of 5%. Same to this model specification and selection process, Tables 3 and 4 show the results for coal and electricity consumption models.

The results for energy consumption are displayed in Table 2. First of all, comparing the results between panel model (1) and spatial panel model (2) in Table 2, the coefficient of spatial lag energy consumption is 0.239, which is significantly positive. It verifies the positive spatial autocorrelation of energy consumption (Liu et al., 2017), which indicates that the tendency of energy consumption in a local province is consistent with those in its neighboring provinces. This spatial pattern might be contributed by the similar economic level, trade, inseparable consumption preference and convenient transportation system between these provinces. The increasing development of transporting energy system has effectively facilitated the energy transmission between these regions in the process of urbanization. From this viewpoint, the province specific energy consumption control strategy enables us to control the total energy consumption throughout the whole China. This kind of demonstration or convergent effect supports the policy of dis-aggregating the total consumption target into smaller targets in different regions (Liu et al., 2017).

Secondly, the impact of urbanization is significantly positive in both panel and spatial panel models, with coefficients of 0.450 and 0.545. The spatial spillover effect of urbanization is negative. Thereby, this result is in contrast with that by Liu et al. (2017), which an insignificant impact of urbanization was reported by using the data from 2006 to 2012, and the different definition of urbanization rate by the permanent resident population ratio. Whereas, in this paper, the sample is taken from 1997 to 2016, and the urbanization rate before 2000 is measured according to the modification by Zhou and Tian (2006). The positive impact of urbanization means that more energy is demanded during the transformation process of current urbanization. The local urbanization processes signify population migration and industry agglomeration into this area and then its energy demand increases accordingly. It is certain that the national policy of promoting the construction of new-type urbanization in China is speed up the process of such urbanization further. As a result, the following questions will be addressed: how will its energy consumption be controlled in the process of new-type urbanization? What will be the different consumption patterns between all these sectors? How does every sector perform any energy governance and management policy? The answers to these questions are crucial for seeking the integral mechanism of controlling energy and its consumption and making sector specific plans to alleviate the energy shortage. Whereas the negative impact of urbanization from neighboring provinces implies a kind of spatial crowding out effect (Funashima and Yoshito, 2019). It indicates when the urbanization in one area increases, energy demand and transmission from its neighbors increases, and the energy supply to the neighbors may decrease. .

Thirdly, the impacts of GDP are all significantly positive in both columns (1) and (2), implying that the regions with higher GDP consume more energy. It is clear that the economic development still relies on energy consumption at the current stage of urbanization. To promote economic growth with less energy consumption, it is imperative to switch to renewable and efficient energy as substitute, and decrease the usage of fossil energy. The spatial spillover effect of GDP is significantly negative, which implies that the higher level of economic development in neighboring provinces will contribute to the reduction of local energy consumption. It reveals that the economic growth in neighboring provinces will not hinder the energy control policy locally. Hence, the economic development policy in neighboring provinces has significant influence on the local control of energy consumption. Such impact of GDP on energy consumption is consistent with the result by Xiao (2014) and Liu et al. (2017).

Fourthly, the impact of industrialization in both panel and spatial models are positive. The spatial spillover effect of industrialization is negative but not significant. Industry is more energy intensive than tertiary as the industrialization of China stays at the development stage of urbanization, which still requires massive energy provision. Both heavy industry and energy intensive industry take a large proportion in the secondary industry. In order to reduce energy consumption, it will be imperative to optimize and upgrade the existing industry structure in the industrialization process. The negative whereas not significant spatial spillover effect from industrialization implies that the industry structure adjustment in neighboring regions is instrumental for the energy control in the whole economy, which indicates some kind of contagion effects from industrialization.

Fifthly, the impact of tertiary is negative but insignificant in the panel model (Zhang and Lin, 2012) and positive but not effect in spatial model, whereas with significantly positive spatial spillover effect. As the tertiary is less energy intensive, it is expected to decrease energy consumption when the tertiary sector expands, and the results imply its function on energy reduction although it does not act significantly till now.

Sixthly, the impact of population is significantly positive, but its spatial spillover effect is significantly negative instead. The local increase of population push the consumption of energy, but the increase of population in neighboring provinces decrease the local energy consumption, which is called crowding out effect (Funashima and Yoshito, 2019), and may be caused by the complete energy transmission system. When the population increases in one area, the demand of energy from neighbors increases, and the supply for the local decreases.

Seventhly, the negative impact of FDI and its negative spatial spillover effects are consistent with technology spillover effects (Saggi, 2002; Peterson, 2008; Shahbaz et al., 2015). These negative impacts encourage further opening-up of economic development without increasing energy consumption (Sbia et al., 2014). The local impact of trade is the same to that of FDI, but the spatial spillover effect of trade show a reserved result, which is negative externality, increasing trade of neighbors increase local energy demand through direct energy transmission and indirect intermediate input.

Eightly, the effect of energy price is negative in both models but not significant in panel model (Liu et al., 2017). It confirms the supply and demand theory in microeconomics. The role of energy price on energy consumption is limited and not so strong as other variables due to price distortion induced by government intervention and it calls for factor marketization (Liu et al., 2017). As for the results of energy structure, the average usage of different type of energy is not helpful to control total energy consumption. On one hand, this result enlighten us to rich the categories of energy, especially the application of clean energy, to improve the disorder of energy types. On the other hand, the aim to reduce coal consumption simply is not appropriate because the high proportion of coal in present China is due to high coal endowment, and it indicates a more efficient policy to adjust energy structure with consideration of China's domestic conditions.

The rest columns from (3) to (8) in Table 2 show the results from spatial Durbin model with interaction terms. Firstly, the spatial lags of energy consumption are all significantly positive. Secondly, the signs of coefficients for eight control variables are consistent with results from the spatial model without interaction term in column (2), although the magnitude of coefficients has slight changes from column (2). Thirdly, the interaction terms in transportation, retail and residential sectors are all significantly negative. Although different results for interaction terms, the local impact of urbanization and sectoral demand on energy consumption are all positive, according to the product between interaction coefficients and the maximum and minimum values of urbanization and sectoral demand, which are shown in table 1. Further, the sign of agriculture and construction sectors are tend to be negative, although insignificant. The coefficients in industry sector is significantly positive. This means that the impact of urbanization on energy consumption depends on these sector energy demand and the contribution of sector energy demand to total energy consumption is highly dependent on the urbanization level, especially in transportation, retail and residential sectors which have significant results. In other words, the impact of urbanization on energy consumption tends to be lower in province with higher sectoral energy demand. The impact of sectoral energy demand on total energy consumption tends to be lower in those highly urbanized provinces. When considering these three sectors (which belong to tertiary sector) with significantly negative interaction terms, on one side, it is clear to see that the sectoral demand impact on total energy consumption in this region tends to be lower if the urbanization level in a region is higher. The negative interaction terms imply that the energy consumption in these sectors in the highly urbanized region is better controlled. Thereby, in the lowly urbanized region, it is more efficient to control sectoral energy consumption by improving urbanization. Specifically, higher concentration and larger density of population, more mobility and housing requirement in the urban area further promote the increasing development of transportation and infrastructure, followed by more demand for oil, electricity and gas consumption, but the energy conservation policies in these sectors are better implemented than other sectors. The twelfth five-year plan requires the implementation of green building and green construction in the construction sector. The thirteenth five-year plan requires to fulfill the China Energy Label system, and the certification system of energy conservation products, and implement the Top-Runner mechanism in the sectors of industry, construction, transportation and consumer goods. In addition, the transportation vehicles and buildings are more energy efficient because of the central heating system and the convenient public transport system extensively used. On the other side, the lower sectoral energy contribution in a region tends to generate higher impact of urbanization in this region, indicating that accelerating the development of tertiary sector is instrumental to alleviate the energy pressure from urbanization and to achieve sustainable development. In contrast, the higher sectoral consumption contribution in a region tends to have lower impact of urbanization level on the total energy consumption in this region. As a result, when the sectoral energy consumption in a region is high, it will be more efficient to control the energy consumption by slowing its urbanization process and instead to improve its urbanization quality and to adjust its urbanization process to be more energy conservation.

Above all, it is suggested to take its urbanization level and sectoral consumption into account when making energy conservation policy for a region. In addition, the different positive results for industry sector indicate that energy consumption is pushed by both industrialization and urbanization, with both positive effect and mutual reinforcement effect. Due to a long process of controlling the energy consumption in industry sector, it is suggested to make policies of upgrading industrial structure, promoting the marketization of factor market and improving the factor substitution elasticity for industry. Finally, the spatial spillover effects of interaction terms are significantly negative in industry and positive in retail, which is in contrast with that of local coefficients. It means that the spatial spillover effects of urbanization inversely depends on the magnitude of sectoral demand level. Thereby, when the demand of industry sector is lower, the spatial spillover effects of urbanization tends to be higher. The spatial spillover effect of industry energy demand is positive, not matter which level of urbanization it is. This indicates a catch up effect of industry energy demand. Because the economic growth is dominated by industry in most provinces, and industrialization is a strategic way to catch up with neighbor provinces in GDP. The spatial effect of retail sector demand tends to be negative in less urbanized area, but positive in highly urbanized area. In those highly urbanized regions, the local energy consumption increases with the growth of the retail sector energy demand in neighbors, which are caused by transportation of energy directly and by trade of service and goods indirectly. Above all, in the process of further deepening urbanization, the spatial spillover effects of sectoral demand tend to increase the local energy consumption. Consequently, it is reasonable for government to forecast similar sectoral structure of energy demand in all regions in order to make effective and efficient national policies and strategies.

The results from coal consumption models are shown in Table 3. In the columns (1) and (2), the impact and spatial spillover effects of control variables are similar to those in energy consumption models, except the local effects of population and energy structure. The change of lifestyle and preference of electrical appliance contribute to the decline of coal consumption. The negative effect of energy structure indicates the contribution of energy type diversification to reduce coal consumption. The interaction terms of industry and transportation sectors are both significantly positive. The urbanization demonstrates positive effects at whatever level of coal demand in industry and transportation sector, and its impact on coal consumption is higher if the coal demand in these two sectors is larger. It indicates mutually reinforcement effects between urbanization and two sectors. It is reasonable to comprehensively consider the inseparable industrialization and urbanization, and the construction of transportation sector into the process of urbanization. Considering the positive or negative contributions from of urbanization and the significant interaction terms of agriculture, retail and residential sectors, the driving force of urbanization is blocked by the coal consumption in these three sectors, which implies good coal control or conservation policy implemented in these sectors. The different result of transportation interaction term in the coal model from energy model may be caused by the improvement of transport system and transformation of energy utilization mode during urbanization. Turning to the spatial spillover effects, both the urbanization and interaction term are significant only in the model for interaction term with industry. The spatial spillover effects in coal models are mixed and confused.

The results from the electricity consumption models are shown in Table 4. The local effects and spatial spillover effects of eight control variables are similar to those in energy models except the local effect of tertiary. The effect of tertiary is positive here because the proportion of electricity consumed in tertiary increases while with decreasing coal demand, and the growth rate of electricity consumed in tertiary is higher than that in industry. The effects of urbanization, sectoral consumption and interaction terms are similar to those in energy consumption models, except industry sector. The negative coefficient of interaction with industry reveals that the electricity consumption is controlled well during urbanization due to the power limitation policy in industrial enterprise. The spatial spillover effects are clearly seen in the model results for agriculture and industry, and the interaction term is negative in the agriculture model (3) and positive in the industry model (4).

Table 2: The estimation results for energy consumption.

Energy	(1)panel	(2)SDM	(3)agriculture	(4)industry	(5)construction	(6)transportation	(7)retail	(8)resident
GDP	0.541^{***}	0.625^{***}	0.641^{***}	0.396^{***}	0.501^{***}	0.551^{***}	0.669^{***}	0.509^{***}
	[0.03]	[0.05]	[0.05]	[0.04]	[0.05]	[0.06]	[0.05]	[0.05]
Industrialization	0.454^{***}	0.341^{***}	0.271^{**}	0.127^{**}	0.302^{***}	0.272^{***}	0.262^{***}	0.324^{***}
	[0.08]	[0.08]	[0.07]	[0.06]	[0.08]	[0.08]	[0.08]	[0.07]
Tertiary	-0.027	0.010	0.075	-0.084	-0.076	-0.016	0.016	0.080
	[0.01]	[0.10]	[0.10]	[0.08]	[0.10]	[0.10]	[0.10]	[0.10]
Population	0.489^{***}	0.822^{***}	0.762^{***}	0.203^{***}	0.381^{***}	0.839^{***}	0.762^{***}	0.792^{***}
	[0.11]	[0.12]	[0.12]	[0.06]	[0.07]	[0.12]	[0.12]	[0.11]
FDI	-0.019^{*}	-0.018^{**}	-0.011	-0.014^{*}	-0.021^{**}	-0.018^{**}	-0.024^{***}	-0.004
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
Trade	0.004	-0.038^{**}	-0.020	-0.043^{***}	-0.053^{***}	-0.024	-0.029	-0.039^{**}
	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]
eprice	-0.023	-0.042^{*}	-0.031	-0.043^{**}	-0.021	-0.040^{*}	-0.046^{**}	0.000
	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]
estructure	0.013^{***}	0.009^{**}	0.009^{**}	0.022^{***}	0.009^{**}	0.010^{**}	0.009^{**}	0.005
	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]

Urbanization	0.450***	0.545***	0.667***	−0.332	0.445***	0.822***	0.845***	1.852***
	[0.08]	[0.08]	[0.18]	[0.20]	[0.10]	[0.16]	[0.10]	[0.18]
Sector			0.276**	0.020	0.090	0.379***	0.449***	0.982***
			[0.12]	[0.10]	[0.07]	[0.11]	[0.08]	[0.11]
Interaction			−0.042	0.100***	−0.008	−0.071**	−0.111***	−0.216***
			[0.03]	[0.03]	[0.02]	[0.03]	[0.02]	[0.03]
W*energy		0.239***	0.210***	0.093**	0.211***	0.233***	0.268***	0.225***
		[0.04]	[0.04]	[0.04]	[0.04]	[0.04]	[0.04]	[0.04]
W*GDP		−0.169**	−0.226***	−0.056	−0.021	−0.206***	−0.273***	−0.187***
		[0.07]	[0.07]	[0.05]	[0.06]	[0.08]	[0.08]	[0.06]
W*industrialization		−0.073	0.021	0.106	0.027	−0.180	−0.015	−0.119
		[0.11]	[0.10]	[0.08]	[0.11]	[0.12]	[0.11]	[0.10]
W*tertiary		−0.283**	−0.211*	0.105	−0.200	−0.391***	−0.312***	−0.422***
		[0.12]	[0.12]	[0.10]	[0.12]	[0.12]	[0.12]	[0.11]
W*population		−0.758***	−0.768***	−0.202***	−0.246**	−0.746***	−0.520***	−0.406***
		[0.15]	[0.16]	[0.08]	[0.10]	[0.15]	[0.16]	[0.14]
W*FDI		−0.043***	−0.028**	−0.009	−0.042***	−0.041***	−0.044***	−0.037***
		[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
W*Trade		0.074***	0.070***	0.054***	0.066***	0.061***	0.065***	0.061***

	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]
W*eprice	0.014	0.010	−0.001	−0.030	0.008	0.005	−0.002
	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]
W*estructure	−0.005	−0.006	−0.001	−0.005	−0.001	−0.005	−0.008
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
W*Urbanization	−0.203*	−0.058	0.575**	0.025	−0.382*	−0.400***	0.172
	[0.12]	[0.20]	[0.28]	[0.14]	[0.22]	[0.14]	[0.28]
W*sector		0.214	0.605***	0.163	−0.127	−0.228*	0.094
		[0.15]	[0.15]	[0.10]	[0.15]	[0.12]	[0.18]
W*Interaction term		−0.043	−0.135***	−0.045*	0.044	0.069**	−0.025
		[0.04]	[0.04]	[0.03]	[0.04]	[0.03]	[0.05]
Wald test spatial Lag	82.77	87.58	40.36	49.16	73.96	71.30	72.31
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
LR test spatial lag	81.43	100.44	61.80	65.83	74.13	73.29	78.99
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Wald test spatial Error	89.16	85.56	36.14	79.96	70.58	73.22	98.43
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
LR test spatial error	86.95	108.66	80.24	92.29	76.14	77.88	98.91
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)

Hausman	44.59	23.42	20.42	28.34	23.07	32.58	100.54	51.63
	(0.0000)	(0.0053)	(0.0399)	(0.2032)	(0.4569)	(0.0006)	(0.0000)	(0.0006)
R-square	0.9447	0.9526	0.9576	0.9734	0.9543	0.9561	0.9540	0.9629

Note: Standard errors for coefficients are in brackets. P-values for statistical tests are in parenthesis. * indicates significant at 10% level, or $p < 0.10$; ** at 5% level or $p < 0.05$; *** at 1% level $p < 0.001$.

Table 3: The estimation results for coal consumption.

Coal	(1)panel	(2)SDM	(3)agriculture	(4)industry	(5)construction	(6)transportation	(7)retail	(8)resident
GDP	0.610^{***}	0.910^{***}	0.945^{***}	0.694^{***}	0.931^{***}	0.776^{***}	0.887^{***}	0.805^{***}
	[0.05]	[0.09]	[0.09]	[0.06]	[0.09]	[0.09]	[0.09]	[0.09]
Industrialization	0.615^{***}	0.507^{***}	0.617^{***}	0.151	0.595^{***}	0.621^{***}	0.528^{***}	0.437^{***}
	[0.13]	[0.13]	[0.12]	[0.09]	[0.13]	[0.13]	[0.13]	[0.12]
Tertiary	0.065	0.406^{**}	0.787^{***}	0.249^{**}	0.523^{***}	0.554^{***}	0.457^{***}	0.423^{***}
	[0.18]	[0.17]	[0.16]	[0.12]	[0.17]	[0.17]	[0.17]	[0.16]
Population	-0.504^{***}	0.078	0.096	-0.008	0.220	0.538^{***}	-0.002	-0.121
	[0.19]	[0.20]	[0.20]	[0.14]	[0.20]	[0.21]	[0.20]	[0.20]
FDI	-0.029^{*}	-0.017	-0.008	-0.001	-0.020	-0.028^{*}	-0.014	0.015
	[0.02]	[0.01]	[0.01]	[0.01]	[0.02]	[0.01]	[0.01]	[0.01]
Trade	-0.084^{***}	-0.128^{***}	-0.076^{**}	-0.123^{***}	-0.122^{***}	-0.111^{***}	-0.128^{***}	-0.118^{***}
	[0.03]	[0.03]	[0.03]	[0.02]	[0.03]	[0.03]	[0.03]	[0.03]
eprice	0.056	0.019	-0.002	-0.053^{**}	0.007	0.060	0.041	0.054
	[0.04]	[0.04]	[0.04]	[0.03]	[0.04]	[0.04]	[0.04]	[0.04]
estructure	-0.006	-0.017^{**}	-0.018^{***}	0.008	-0.017^{**}	-0.017^{**}	-0.015^{**}	-0.021^{***}
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]

Urbanization	0.421***	0.675***	0.964***	−0.424	0.625***	0.427**	0.779***	2.105***
	[0.14]	[0.14]	[0.16]	[0.26]	[0.16]	[0.18]	[0.14]	[0.23]
Sector			0.619***	0.045	−0.215	−0.420***	0.389***	0.926***
			[0.11]	[0.14]	[0.14]	[0.14]	[0.09]	[0.12]
Interaction term			−0.137***	0.131***	0.049	0.111***	−0.097***	−0.217***
			[0.03]	[0.04]	[0.04]	[0.04]	[0.02]	[0.03]
W*coal		0.242***	0.217***	0.302***	0.264***	0.281***	0.272***	0.191***
		[0.04]	[0.04]	[0.04]	[0.04]	[0.04]	[0.04]	[0.04]
W*GDP		−0.432***	−0.288**	−0.433***	−0.419***	−0.267**	−0.425***	−0.470***
		[0.11]	[0.11]	[0.08]	[0.11]	[0.11]	[0.11]	[0.11]
W*Industrialization		0.252	0.072	0.485***	0.077	−0.021	0.227	0.209
		[0.18]	[0.17]	[0.12]	[0.18]	[0.17]	[0.18]	[0.17]
W*tertiary		−0.622***	−0.799***	0.065	−0.809***	−0.843***	−0.661***	−0.729***
		[0.21]	[0.19]	[0.15]	[0.21]	[0.20]	[0.21]	[0.20]
W*population		−0.451*	−1.173***	0.588***	−0.706***	−1.254***	−0.254	−0.035
		[0.26]	[0.26]	[0.19]	[0.26]	[0.28]	[0.26]	[0.25]
W*Fdi		−0.099***	−0.076***	−0.042***	−0.088***	−0.077***	−0.099***	−0.103***
		[0.02]	[0.02]	[0.01]	[0.02]	[0.02]	[0.02]	[0.02]
W*Trade		0.040	−0.015	0.012	0.031	0.023	0.035	0.015

	[0.04]	[0.03]	[0.03]	[0.04]	[0.04]	[0.04]	[0.03]
W*eprice	0.045	0.022	0.020	0.025	0.032	0.031	0.038
	[0.04]	[0.04]	[0.03]	[0.04]	[0.04]	[0.04]	[0.04]
W*estructure	0.007	−0.000	0.006	0.004	0.004	0.006	0.003
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
W*Urbanization	0.013	0.327	1.097***	0.163	0.131	−0.059	0.816**
	[0.21]	[0.23]	[0.36]	[0.21]	[0.24]	[0.20]	[0.33]
W*sector		0.748***	0.724***	0.533***	0.540***	−0.278**	0.366**
		[0.15]	[0.19]	[0.16]	[0.17]	[0.13]	[0.17]
W*Interaction-term		−0.215***	−0.196***	−0.133***	−0.158***	0.068**	−0.077*
		[0.04]	[0.05]	[0.04]	[0.04]	[0.03]	[0.04]
Wald test-spatial Lag	110.86	151.91	87.55	114.61	129.55	98.22	135.89
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
LR test-spatial lag	103.83	182.51	119.57	120.53	142.43	95.24	135.45
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Wald test-spatial Error	132.21	195.53	87.55	141.11	153.98	116.34	162.86
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
LR test-spatial error	124.67	201.14	132.06	138.31	154.82	112.93	163.73
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)

Hausman	63.60	61.66	241.68	129.23	153.03	285.55	318.65	304.35
	(0.0000)	(0.0000)	(0.0000)	(0.0003)	(0.0000)	(0.0000)	0.0000	0.0000
R-square	0.8333	0.8648	0.8877	0.9324	0.8663	0.8711	0.8669	0.8867

Note: Standard errors for coefficients are in brackets. P-values for statistical tests are in parenthesis. * indicates significant at 10% level, or $p < 0.10$; ** at 5% level or $p < 0.05$; *** at 1% level $p < 0.001$.

Table 4: The estimation results for electricity consumption.

Electricity	(1)panel	(2)SDM	(3)agriculture	(4)industry	(5)construction	(6)transportation	(7)retail	(8)resident
GDP	0.587***	0.700***	0.696***	0.284***	0.720***	0.741***	0.705***	0.643***
	[0.03]	[0.06]	[0.06]	[0.03]	[0.06]	[0.06]	[0.06]	[0.06]
Industrialization	0.649***	0.375***	0.306***	−0.126***	0.326***	0.188**	0.343***	0.272***
	[0.09]	[0.09]	[0.08]	[0.04]	[0.08]	[0.08]	[0.08]	[0.08]
Tertiary	0.487***	0.335***	0.233***	−0.072	0.408***	0.283***	0.405***	0.210*
	[0.12]	[0.11]	[0.11]	[0.06]	[0.11]	[0.11]	[0.11]	[0.11]
Population	1.018***	0.926***	0.907***	0.357***	0.882***	0.904***	0.793***	0.733***
	[0.13]	[0.13]	[0.13]	[0.07]	[0.13]	[0.13]	[0.13]	[0.13]
FDI	0.013	0.022**	0.028***	0.007	0.022**	0.034***	0.019**	0.018*
	[0.01]	[0.01]	[0.01]	[0.00]	[0.01]	[0.01]	[0.01]	[0.01]
Trade	−0.052**	−0.033	−0.027	−0.004	−0.033	−0.028	−0.059***	−0.017
	[0.02]	[0.02]	[0.02]	[0.01]	[0.02]	[0.02]	[0.02]	[0.02]
eprice	−0.020	0.013	0.032	−0.001	0.004	−0.006	0.017	−0.008
	[0.03]	[0.03]	[0.02]	[0.01]	[0.02]	[0.02]	[0.02]	[0.02]
estructure	0.010	0.007	0.010**	−0.003	0.004	0.007	0.007	0.006
	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]

Urbanization	0.867***	0.694***	0.761***	0.650***	0.789***	1.122***	0.551***	0.854***
	[0.09]	[0.09]	[0.15]	[0.11]	[0.10]	[0.10]	[0.10]	[0.15]
Sector			0.141	0.915***	0.647***	1.066***	0.144	0.514***
			[0.12]	[0.07]	[0.11]	[0.12]	[0.10]	[0.12]
Interaction-term			−0.011	−0.075***	−0.153***	−0.259***	−0.006	−0.092***
			[0.03]	[0.02]	[0.03]	[0.03]	[0.03]	[0.03]
W*electricity		0.310***	0.293***	0.074	0.321***	0.315***	0.370***	0.323***
		[0.04]	[0.04]	[0.05]	[0.04]	[0.04]	[0.04]	[0.04]
W*GDP		−0.139*	−0.187**	0.004	−0.193**	−0.219***	−0.157**	−0.160**
		[0.08]	[0.08]	[0.04]	[0.08]	[0.08]	[0.08]	[0.08]
W*Industria-		0.027	−0.005	0.135**	0.100	−0.175	−0.016	−0.148
lization		[0.12]	[0.11]	[0.07]	[0.12]	[0.12]	[0.12]	[0.12]
W*tertiary		−0.177	−0.090	0.168**	−0.142	−0.470***	−0.271**	−0.373***
		[0.14]	[0.13]	[0.07]	[0.14]	[0.13]	[0.13]	[0.14]
W*population		−0.753***	−0.916***	−0.321***	−0.604***	−0.693***	−0.650***	−0.678***
		[0.17]	[0.17]	[0.09]	[0.17]	[0.16]	[0.16]	[0.17]
W*FDI		−0.120***	−0.081***	−0.034***	−0.107***	−0.071***	−0.120***	−0.106***
		[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
W*Trade		0.009	0.028	0.002	0.024	0.015	0.031	−0.011

	[0.02]	[0.02]	[0.01]	[0.02]	[0.02]	[0.02]	[0.02]
W*eprice	−0.081***	−0.087***	−0.032**	−0.109***	−0.103***	−0.086***	−0.072***
	[0.03]	[0.02]	[0.01]	[0.02]	[0.02]	[0.02]	[0.02]
W*estructure	−0.000	0.001	−0.003	−0.002	0.002	0.001	−0.002
	[0.01]	[0.01]	[0.00]	[0.01]	[0.01]	[0.01]	[0.01]
W*Urbanization	−0.111	0.157	−0.527***	−0.170	−0.188	0.014	−0.136
	[0.14]	[0.19]	[0.14]	[0.14]	[0.15]	[0.14]	[0.20]
W*sector		0.393**	−0.237**	−0.065	0.093	0.072	0.095
		[0.16]	[0.11]	[0.15]	[0.17]	[0.13]	[0.16]
W*Interaction-term		−0.101**	0.062**	0.022	−0.004	−0.046	−0.014
		[0.04]	[0.02]	[0.04]	[0.04]	[0.03]	[0.04]
Wald test-spatial lag	124.32	119.67	54.25	114.96	100.04	136.73	96.71
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
LR test-spatial lag	145.64	144.29	73.89	146.00	130.01	178.21	134.03
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Wald test-spatial Error	131.44	122.99	69.93	122.83	96.61	143.10	117.30
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
LR test-spatial error	112.08	126.08	78.31	124.73	111.77	142.35	111.40
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)

Hausman	61.61	51.99	53.44	35.94	90.33	95.46	46.94	96.26
	(0.0000)	(0.0001)	(0.0003)	(0.0418)	(0.0000)	(0.0000)	(0.0023)	(0.0000)
R-square	0.9507	0.9599	0.9643	0.9915	0.9631	0.9655	0.9612	0.9627

Note: Standard errors for coefficients are in brackets. P-values for statistical tests are in parenthesis. * indicates significant at 10% level, or $p < 0.10$; ** at 5% level or $p < 0.05$; *** at 1% level $p < 0.001$.

4.3 Effects of spatial decomposition

Although the point estimations of spatial models above provide the significant coefficients and some intuitive relationships, they are not sufficient to explain the marginal effects of independent variable on dependent variable due to feedback loop effects. Thereby, in this paper, spatial decomposition effects are considered into the modelling process. The results of spatial decomposition with direct, indirect and total effects of independent variables in spatial Durbin models are reported in Tables 5, 6, 7 respectively. In each table, column (2) is the result from the spatial model without interaction term, and columns (3) to (8) correspond to the results from the spatial models with interaction terms of agriculture, industry, construction, transport, retail, and residential sectors, respectively. It is clear that there are some differences from these results derived from the feedback loop effects.

In all the three tables, the direct and total effects of GDP and industrialization are all positive, indicating that the economic growth and industrialization are the main driving forces of energy consumption, even at disaggregated level. The indirect effects of industrialization are all positive despite sometimes insignificant, as industrialization is regarded as a main catalyst for local economic growth and industry consumes the largest energy among all the sectors. The governments have been expanding the secondary industry by developing diverse industrial parks (Jiang and Ji, 2016). To catch up with the economic growth of neighboring regions, local governments usually tend to imitate their neighbors' industrial policy, which result in positive spatial spillover effects of industrialization at this regional level. The direct, indirect and total effects of FDI are all negative except the positive direct effect in electricity model, indicating that the technology spillover is instrumental in improving energy efficiency and reducing energy consumption, while the increase demand of electricity has not been canceled out. The direct effects of trade in energy, coal and electricity models are negative, which reveal the technology spillover effects. As for energy price, the direct and total effects in energy models are negative in accordance with the supply and demand theory in microeconomics. While the direct effect of energy price in coal and electricity models are induced by the government intervention policy on coal and electricity, such as carbon tax and power rationing.

In Table 5, the direct and total effects of urbanization are positive in column (2). The direct effects of urbanization, sectoral consumption and the interaction term, in the four models with interaction terms of transportation, retail and residential energy demand are all significant, whereas the agriculture, industry and construction sectors are exceptional. Although the coefficients for agriculture and construction energy demand and its interaction term are not significant, they shows same signs with other four sectors. These results indicate that the direct effect of urbanization on total energy consumption is partially revealed and restrained from these five sectors, and the energy conservation policy in these sectors is efficient. From the perspective of total effects, the signs of urbanization, sector and interaction are consistent between the six sectors. The impact of urbanization depends on the energy demand in sectors, and urbanization is significantly positive when the sectoral demand is low, but may turn to negative when the sectoral demand increases. The elasticity of urbanization on energy consumption depends on urbanization level and sectoral consumption level in a specific region. Urbanization process promotes the spatial agglomeration of population and production, stimulates the increasing demands for infrastructure, transportation, construction and living appliance.

In Table 6, the direct and total effects of urbanization are significantly positive in column (2). The direct effects in the models with agriculture, retail, construction and residential demand are similar to those in Table 5. Industry is the main consumer of coal, and its effect is driven more by industrialization than by urbanization. The positive interaction with industry show that urbanization and industry demand jointly push coal consumption. The construction sector is not the primary user of coal, and it is reasonable to explain such insignificant result of direct effects. The indirect effects of interaction terms are negative in agriculture, industry, construction, transportation and residential sectors, indicating the spatial spillover effect of urbanization is moderated by demand from these sectors and the net effects depend on the level of sectoral coal demand. The total effects of urbanization in columns (3) to (8) are significant and the interaction terms are negative.

In Table 7, the direct and total effects of urbanization are significantly positive in column (2). The significant direct effects of urbanization and the negative interaction terms show that direct effects of urbanization on electricity consumption are restrained well through all the sectors whereas not significant in agriculture and retail sectors. It shows different result from energy model in industry sector. The indirect effect of urbanization interacts with sectors negatively apart from industry sector. Urbanization and industry demand jointly stimulate electricity consumption. The total effects of urbanization are all positive and interact with all sectors negatively, indicating efficient electricity policy in six sectors in the process of urbanization.

Summing up, the results of direct, indirect and total effects of urbanization are not consistent, and vary with energy types, sectors and urbanization levels of regions. The regional energy conservation policies specified by energy type and sector, are more efficient, concrete and precise, when considering the economic development and urbanization level of its neighboring regions.

Table 5: Spatial effects decomposition results for energy consumption models.

Energy	(2)SDM	(3)agriculture	(4)industruction	(5)constrution	(6)transportation	(7)retail	(8)resident
Direct effects							
GDP	0.625***	0.635***	0.396***	0.510***	0.546***	0.661***	0.504***
	[0.05	[0.05]	[0.04]	[0.05]	[0.06]	[0.05]	[0.05]
Industrialization	0.337***	0.270***	0.128**	0.306***	0.255***	0.263***	0.315***
	[0.07]	[0.07]	[0.06]	[0.07]	[0.08]	[0.08]	[0.07]
tertiary	−0.015	0.061	−0.079	−0.093	−0.052	−0.017	0.045
	[0.09]	[0.10]	[0.08]	[0.10]	[0.10]	[0.09]	[0.09]
Population	0.758***	0.704***	0.194***	0.364***	0.781***	0.721***	0.766***
	[0.11]	[0.11]	[0.06]	[0.07]	[0.11]	[0.11]	[0.10]
FDI	−0.023***	−0.013	−0.014**	−0.025***	−0.022**	−0.030***	−0.007
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
Trade	−0.031	−0.013	−0.040***	−0.048**	−0.017	−0.021	−0.033*
	[0.02]	[0.02]	[0.01]	[0.02]	[0.02]	[0.02]	[0.02]
eprice	−0.042*	−0.031	−0.044***	−0.025	−0.041*	−0.047**	−0.001
	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]
estructure	0.009*	0.009**	0.022***	0.009**	0.010**	0.009**	0.004

	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Urbanization	0.535***	0.678***	−0.309	0.455***	0.805***	0.825***	1.911***
	[0.08]	[0.19]	[0.21]	[0.10]	[0.16]	[0.10]	[0.19]
Sector		0.306**	0.047	0.109	0.381***	0.442***	1.016***
		[0.13]	[0.11]	[0.07]	[0.11]	[0.08]	[0.11]
Interaction term		−0.049	0.094***	−0.013	−0.070**	−0.108***	−0.225***
		[0.03]	[0.03]	[0.02]	[0.03]	[0.02]	[0.03]
Indirect effects							
GDP	−0.023	−0.106	−0.023	0.098	−0.091	−0.114	−0.085
	[0.07]	[0.07]	[0.05]	[0.06]	[0.08]	[0.08]	[0.07]
Industrialization	0.004	0.035	0.126	0.103	−0.151	0.059	−0.064
	[0.12]	[0.12]	[0.09]	[0.12]	[0.14]	[0.13]	[0.11]
Tertiary	−0.341**	−0.235*	0.099	−0.265*	−0.481***	−0.391***	−0.489***
	[0.14]	[0.13]	[0.10]	[0.14]	[0.14]	[0.14]	[0.13]
Population	−0.733***	−0.735***	−0.193**	−0.197*	−0.684***	−0.415**	−0.289*
	[0.18]	[0.18]	[0.08]	[0.12]	[0.17]	[0.20]	[0.16]
FDI	−0.058***	−0.036**	−0.010	−0.054***	−0.055***	−0.064***	−0.045***
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]

Trade	0.078***	0.080***	0.053***	0.065**	0.069***	0.074***	0.065***
	[0.03]	[0.02]	[0.02]	[0.03]	[0.02]	[0.02]	[0.02]
eprice	0.008	0.004	−0.005	−0.041	−0.002	−0.010	−0.003
	[0.03]	[0.02]	[0.02]	[0.03]	[0.03]	[0.03]	[0.02]
estructure	−0.004	−0.005	0.001	−0.004	0.002	−0.003	−0.008
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
urbanization	−0.096	0.075	0.552*	0.132	−0.246	−0.233	0.682**
	[0.14]	[0.23]	[0.30]	[0.16]	[0.24]	[0.17]	[0.31]
sector		0.315*	0.632***	0.206*	−0.048	−0.134	0.371*
		[0.18]	[0.16]	[0.11]	[0.17]	[0.15]	[0.20]
interaction		−0.060	−0.130***	−0.053*	0.034	0.049	−0.087*
		[0.05]	[0.04]	[0.03]	[0.05]	[0.04]	[0.05]
Total effects							
GDP	0.602***	0.529***	0.373***	0.608***	0.455***	0.547***	0.419***
	[0.06]	[0.07]	[0.04]	[0.06]	[0.08]	[0.08]	[0.07]
Industrialization	0.341**	0.304**	0.254***	0.409***	0.104	0.323**	0.250*
	[0.14]	[0.13]	[0.09]	[0.14]	[0.15]	[0.15]	[0.13]
Tertiary	−0.356**	−0.174	0.020	−0.358**	−0.534***	−0.408**	−0.444***

	[0.16]	[0.15]	[0.11]	[0.16]	[0.16]	[0.16]	[0.14]
Population	0.025	−0.031	0.001	0.167	0.097	0.305	0.477**
	[0.22]	[0.21]	[0.09]	[0.13]	[0.21]	[0.24]	[0.20]
FDI	−0.081***	−0.050***	−0.024**	−0.079***	−0.077***	−0.093***	−0.052***
	[0.02]	[0.02]	[0.01]	[0.02]	[0.02]	[0.02]	[0.02]
Trade	0.047	0.067**	0.013	0.018	0.052*	0.053*	0.031
	[0.03]	[0.03]	[0.02]	[0.03]	[0.03]	[0.03]	[0.03]
eprice	−0.033	−0.028	−0.049**	−0.066*	−0.044	−0.057	−0.004
	[0.04]	[0.03]	[0.02]	[0.04]	[0.03]	[0.04]	[0.03]
estructure	0.005	0.004	0.023***	0.005	0.013	0.006	−0.003
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
Urbanization	0.439**	0.753***	0.243	0.587***	0.559**	0.592***	2.593***
	[0.18]	[0.29]	[0.31]	[0.19]	[0.25]	[0.21]	[0.37]
Sector		0.621***	0.679***	0.315**	0.333*	0.308*	1.386***
		[0.21]	[0.15]	[0.13]	[0.18]	[0.16]	[0.23]
Interaction		−0.108**	−0.036	−0.065**	−0.036	−0.059	−0.312***
		[0.06]	[0.04]	[0.03]	[0.05]	[0.04]	[0.06]

Note: Standard errors for coefficients are in brackets. * indicates significant at 10% level, or $p < 0.10$; ** indicates significant at 5% level or $p < 0.05$; *** indicates significant at 1% level $p < 0.001$.

Table 6: Spatial effects decomposition results for coal consumption models.

Coal	(2)SDM	(3)agriculture	(4)industruction	(5)constrution	(6)transportation	(7)retail	(8)resident
Direct effects							
GDP	0.891***	0.941***	0.668***	0.915***	0.773***	0.869***	0.784***
	[0.09]	[0.09]	[0.06]	[0.09]	[0.09]	[0.09]	[0.08]
Industrialization	0.538***	0.627***	0.214**	0.613***	0.631***	0.562***	0.452***
	[0.12]	[0.12]	[0.09]	[0.12]	[0.12]	[0.13]	[0.12]
Tertiary	0.357**	0.735***	0.269**	0.452***	0.475***	0.398**	0.376**
	[0.16]	[0.15]	[0.11]	[0.16]	[0.16]	[0.16]	[0.15]
Population	0.025	−0.015	0.059	0.138	0.397**	−0.041	−0.134
	[0.20]	[0.19]	[0.14]	[0.19]	[0.20]	[0.19]	[0.19]
FDI	−0.027*	−0.015	−0.006	−0.030**	−0.038***	−0.025*	−0.007
	[0.01]	[0.01]	[0.01]	[0.02]	[0.01]	[0.01]	[0.01]
Trade	−0.126***	−0.076**	−0.124***	−0.120***	−0.110***	−0.125***	−0.117***
	[0.03]	[0.03]	[0.02]	[0.03]	[0.03]	[0.03]	[0.03]
eprice	0.024	0.000	−0.053**	0.009	0.064*	0.045	0.056
	[0.04]	[0.04]	[0.03]	[0.04]	[0.04]	[0.04]	[0.04]
estructure	−0.017**	−0.019***	0.009*	−0.016**	−0.016**	−0.014*	−0.021***

	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
Urbanization	0.699***	1.025***	−0.299	0.655***	0.451**	0.791***	2.197***
	[0.14]	[0.17]	[0.27]	[0.16]	[0.19]	[0.14]	[0.25]
Sector		0.710***	0.114	−0.160	−0.368**	0.374***	0.971***
		[0.11]	[0.14]	[0.14]	[0.16]	[0.10]	[0.13]
Interaction term		−0.162***	0.110***	0.035	0.095**	−0.093***	−0.227***
		[0.03]	[0.04]	[0.04]	[0.04]	[0.02]	[0.03]
Indirect effects							
GDP	−0.260**	−0.101	−0.289***	−0.212*	−0.059	−0.227*	−0.364***
	[0.12]	[0.12]	[0.09]	[0.12]	[0.12]	[0.12]	[0.11]
Industrialization	0.455**	0.233	0.681***	0.275	0.177	0.450**	0.325*
	[0.20]	[0.19]	[0.15]	[0.20]	[0.20]	[0.21]	[0.18]
Tertiary	−0.639***	−0.754***	0.179	−0.849***	−0.885***	−0.685***	−0.760***
	[0.23]	[0.21]	[0.17]	[0.24]	[0.23]	[0.24]	[0.21]
Population	−0.540*	−1.387***	0.740***	−0.842***	−1.437***	−0.351	−0.094
	[0.31]	[0.29]	[0.25]	[0.32]	[0.34]	[0.32]	[0.29]
FDI	−0.126***	−0.092***	−0.055***	−0.117***	−0.108***	−0.129***	−0.117***
	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]
Trade	0.008	−0.034	−0.030	0.003	−0.005	0.005	−0.005

	[0.04]	[0.04]	[0.03]	[0.04]	[0.04]	[0.04]	[0.04]
eprice	0.064	0.024	0.005	0.032	0.061	0.053	0.055
	[0.05]	[0.04]	[0.03]	[0.05]	[0.05]	[0.05]	[0.04]
estructure	0.004	−0.005	0.011	0.000	−0.000	0.003	−0.001
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
Urbanization	0.206	0.629**	1.237***	0.375	0.283	0.160	1.370***
	[0.26]	[0.28]	[0.47]	[0.29]	[0.32]	[0.27]	[0.40]
Sector		1.057***	0.957***	0.587***	0.527**	−0.216	0.617***
		[0.19]	[0.25]	[0.21]	[0.23]	[0.17]	[0.20]
Interaction term		−0.293***	−0.203***	−0.147***	−0.159***	0.052	−0.134***
		[0.05]	[0.06]	[0.06]	[0.06]	[0.04]	[0.05]
Total effects							
GDP	0.632***	0.840***	0.379***	0.703***	0.714***	0.643***	0.420***
	[0.11]	[0.11]	[0.09]	[0.12]	[0.12]	[0.12]	[0.11]
Industrialization	0.993***	0.860***	0.894***	0.888***	0.808***	1.012***	0.778***
	[0.23]	[0.21]	[0.17]	[0.24]	[0.23]	[0.25]	[0.21]
Tertiary	−0.282	−0.019	0.449**	−0.397	−0.410	−0.287	−0.384
	[0.27]	[0.24]	[0.20]	[0.27]	[0.27]	[0.27]	[0.23]
Population	−0.515	−1.402***	0.799**	−0.703*	−1.040***	−0.393	−0.229

	[0.38]	[0.34]	[0.31]	[0.39]	[0.39]	[0.40]	[0.34]
FDI	-0.153^{***}	-0.107^{***}	-0.061^{**}	-0.147^{***}	-0.146^{***}	-0.154^{***}	-0.110^{***}
	[0.03]	[0.03]	[0.02]	[0.03]	[0.03]	[0.03]	[0.03]
Trade	-0.117^{**}	-0.110^{**}	-0.154^{***}	-0.117^{**}	-0.115^{**}	-0.120^{**}	-0.122^{***}
	[0.05]	[0.05]	[0.04]	[0.05]	[0.05]	[0.05]	[0.05]
eprice	0.088	0.024	-0.049	0.041	0.125^{*}	0.098	0.112^{**}
	[0.06]	[0.06]	[0.05]	[0.07]	[0.07]	[0.07]	[0.05]
estructure	-0.013	-0.024	0.020	-0.016	-0.016	-0.011	-0.022
	[0.02]	[0.02]	[0.01]	[0.02]	[0.02]	[0.02]	[0.01]
Urbanization	0.905^{***}	1.654^{***}	0.938^{*}	1.030^{***}	0.735^{*}	0.951^{***}	3.567^{***}
	[0.32]	[0.36]	[0.54]	[0.37]	[0.42]	[0.34]	[0.52]
Sector		1.768^{***}	1.102^{***}	0.426	0.159	0.159	1.588^{***}
		[0.25]	[0.27]	[0.29]	[0.32]	[0.22]	[0.24]
Interaction term		-0.456^{***}	-0.093	-0.112	-0.064	-0.041	-0.361^{***}
		[0.07]	[0.07]	[0.07]	[0.08]	[0.06]	[0.06]

Note: Standard errors for coefficients are in brackets. * indicates significant at 10% level, or $p < 0.10$; ** indicates significant at 5% level or $p < 0.05$; *** indicates significant at 1% level $p < 0.001$.

Table 7: Spatial effects decomposition results for electricity consumption models.

Electricity	(2)SDM	(3)agriculture	(4)industruction	(5)constrution	(6)transportation	(7)retail	(8)resident
Direct effects							
GDP	0.713***	0.700***	0.286***	0.728***	0.745***	0.725***	0.652***
	[0.06]	[0.06]	[0.03]	[0.06]	[0.05]	[0.06]	[0.06]
Industrialization	0.390***	0.311***	−0.125***	0.348***	0.167**	0.356***	0.258***
	[0.08]	[0.08]	[0.04]	[0.08]	[0.08]	[0.08]	[0.08]
Tertiary	0.327***	0.232**	−0.066	0.408***	0.233**	0.387***	0.170
	[0.11]	[0.10]	[0.05]	[0.10]	[0.10]	[0.10]	[0.10]
Population	0.857***	0.819***	0.345***	0.831***	0.844***	0.727***	0.707***
	[0.13]	[0.12]	[0.07]	[0.13]	[0.12]	[0.13]	[0.13]
FDI	0.007	0.019*	0.006	0.008	0.026**	0.001	0.005
	[0.01]	[0.01]	[0.00]	[0.01]	[0.01]	[0.01]	[0.01]
Trade	−0.032	−0.024	−0.003	−0.030	−0.025	−0.055***	−0.017
	[0.02]	[0.02]	[0.01]	[0.02]	[0.02]	[0.02]	[0.02]
eprice	0.003	0.022	−0.002	−0.011	−0.020	0.004	−0.019
	[0.03]	[0.03]	[0.01]	[0.03]	[0.03]	[0.03]	[0.03]
estructure	0.007	0.010**	−0.003	0.003	0.007	0.008	0.006

	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Urbanization	0.711***	0.821***	0.646***	0.806***	1.152***	0.593***	0.886***
	[0.09]	[0.15]	[0.10]	[0.10]	[0.11]	[0.10]	[0.14]
Sector		0.209*	0.918***	0.678***	1.139***	0.176**	0.563***
		[0.12]	[0.07]	[0.11]	[0.11]	[0.09]	[0.11]
Interaction term		−0.027	−0.076***	−0.160***	−0.274***	−0.017	−0.102***
		[0.03]	[0.02]	[0.03]	[0.03]	[0.02]	[0.03]
Indirect effects							
GDP	0.103	0.023	0.027	0.052	0.021	0.152*	0.067
	[0.08]	[0.08]	[0.05]	[0.09]	[0.08]	[0.09]	[0.08]
Industrialization	0.186	0.100	0.129*	0.261*	−0.163	0.149	−0.090
	[0.14]	[0.14]	[0.07]	[0.15]	[0.16]	[0.15]	[0.16]
Tertiary	−0.097	−0.037	0.168**	−0.022	−0.512***	−0.175	−0.412**
	[0.16]	[0.16]	[0.07]	[0.16]	[0.17]	[0.17]	[0.18]
Population	−0.625***	−0.853***	−0.317***	−0.444**	−0.553***	−0.524**	−0.592***
	[0.22]	[0.20]	[0.09]	[0.21]	[0.20]	[0.22]	[0.21]
FDI	−0.150***	−0.095***	−0.036***	−0.134***	−0.080***	−0.160***	−0.134***
	[0.02]	[0.02]	[0.01]	[0.02]	[0.02]	[0.02]	[0.02]
Trade	−0.003	0.028	0.003	0.020	0.010	0.016	−0.020

	[0.03]	[0.03]	[0.01]	[0.03]	[0.03]	[0.03]	[0.03]
eprice	−0.099***	−0.101***	−0.034**	−0.145***	−0.141***	−0.115***	−0.101***
	[0.03]	[0.03]	[0.01]	[0.03]	[0.03]	[0.03]	[0.03]
estructure	0.004	0.004	−0.003	−0.001	0.006	0.005	−0.000
	[0.01]	[0.01]	[0.00]	[0.01]	[0.01]	[0.01]	[0.01]
Urbanization	0.130	0.476*	−0.513***	0.100	0.208	0.300	0.170
	[0.19]	[0.26]	[0.15]	[0.20]	[0.21]	[0.21]	[0.26]
Sector		0.556***	−0.182	0.194	0.567**	0.177	0.342*
		[0.22]	[0.11]	[0.20]	[0.22]	[0.17]	[0.21]
Interaction term		−0.133**	0.060**	−0.037	−0.113**	−0.069	−0.057
		[0.05]	[0.03]	[0.05]	[0.06]	[0.05]	[0.05]
Total effects							
GDP	0.816***	0.723***	0.313***	0.780***	0.766***	0.877***	0.719***
	[0.08]	[0.08]	[0.04]	[0.09]	[0.08]	[0.010]	[0.09]
Industrialization	0.576***	0.411**	0.004	0.609***	0.004	0.504***	0.168
	[0.17]	[0.16]	[0.08]	[0.18]	[0.19]	[0.19]	[0.19]
Tertiary	0.231	0.195	0.103	0.386*	−0.279	0.213	−0.242
	[0.20]	[0.19]	[0.08]	[0.20]	[0.21]	[0.21]	[0.22]
Population	0.232	−0.034	0.028	0.387	0.290	0.202	0.115

	[0.27]	[0.26]	[0.10]	[0.26]	[0.26]	[0.28]	[0.27]
FDI	−0.142***	−0.076***	−0.030***	−0.126***	−0.054**	−0.160***	−0.129***
	[0.02]	[0.02]	[0.01]	[0.02]	[0.02]	[0.03]	[0.02]
Trade	−0.035	0.004	−0.000	−0.010	−0.015	−0.040	−0.037
	[0.04]	[0.04]	[0.02]	[0.04]	[0.04]	[0.04]	[0.04]
eprice	−0.096**	−0.079*	−0.036**	−0.156***	−0.161***	−0.111**	−0.120***
	[0.04]	[0.04]	[0.02]	[0.05]	[0.04]	[0.05]	[0.04]
estructure	0.011	0.014	−0.006	0.002	0.013	0.013	0.005
	[0.01]	[0.01]	[0.00]	[0.01]	[0.01]	[0.01]	[0.01]
Urbanization	0.841***	1.297***	0.133	0.906***	1.360***	0.893***	1.056***
	[0.24]	[0.34]	[0.15]	[0.25]	[0.26]	[0.26]	[0.28]
Sector		0.765***	0.736***	0.873***	1.705***	0.353*	0.905***
		[0.27]	[0.11]	[0.24]	[0.26]	[0.18]	[0.21]
Interaction term		−0.160**	−0.016	−0.197***	−0.388***	−0.086*	−0.159***
		[0.07]	[0.02]	[0.06]	[0.06]	[0.05]	[0.05]

Note: Standard errors for coefficients are in brackets. * indicates significant at 10% level, or $p < 0.10$; ** indicates significant at 5% level or $p < 0.05$; *** indicates significant at 1% level $p < 0.001$.

5 Conclusions and policy implications

Using the collated panel data set from 1997 to 2016 across 30 provinces in China, this paper investigates the impacts of urbanization on energy, coal and electricity consumptions. By developing spatial panel model with interaction terms, and comparing it with panel and spatial panel model without interaction terms, significant results have been produced in section 4, which help draw the following conclusions and discuss policy implications.

First, there has been significant spatial autocorrelation present in the data of three categories of energy consumption. It indicates the clustering patterns of energy consumption at provincial level. As disaggregating global energy conservation policy into smaller local ones is effective (Liu et al., 2017), geographical patterns should be considered into the process of making disaggregated energy control policy at province level.

Second, economic growth has positive impacts on energy consumption significantly in China, which is in accordance with conservation hypothesis (Sadorsky, 2010; Nasreen and Anwar, 2014; Liu et al., 2017). Considering the continuing economic growth in China, its energy consumption can be controlled by increasing its energy efficiency as one strategy, which is consistent with the China's five-year target in mandatorily constraining energy intensity. The positive effect of industrialization on energy consumption confirms the rationales for factor marketization, and industrial structure upgrading and optimization, because China is moving towards late-/post-industrialization (Li and Lin, 2015) and China's industry in particular manufacturing industry such as iron and steel industry tends to be energy intensive (Liu et al., 2012; Chen et al., 2014). The reduction of energy consumption at the late-/post industrialization stage, suggests a need of further industrialization in China (Li and Lin, 2015). The positive indirect effects of industrialization on energy, coal and electricity consumptions highlight the increasing importance of coordinating the development policies for industrialization between provinces. The insignificant direct impact of tertiary in the energy model and significant positive impact in the coal and electricity models show that the development of service industry is less energy intensive but still needs more coal and electricity (Zhang and Lin, 2012), which implies the necessity to develop a modern and sustainable service sector. The negative indirect and total effect of tertiary (Liu et al., 2017) confirm that the development of tertiary helps to control energy consumption, whereas the role is played through spatial spillover effects at present. It appeals for industry structure optimization and upgrading. The negative effects of FDI imply the demand for more efficient reform and open-up policies in order to further attract overseas high technology and funding (Sbia et al., 2014). It appeals for effective absorption of energy efficient technology transferred through FDI and trade (Nasreen and Anwar, 2014) and making full use of management skills from FDI. The impacts of population on energy and electricity are significantly positive, but negative on coal consumption. This finding reveals and verifies the preference of clean energy when population increases (Liu, 2009), especially when the people migrate into urban area. In addition, the results for energy price inspires factor marketization. The results of energy structure appeal for reasonable composition of energy forms considering the resource endowment of China.

Third, urbanization has been proven a positive determinant of energy, coal and electricity consumptions (Malick and Mahalik, 2014; Zhou et al., 2015) as increasing urbanization requires more energy uses. It is imperative to formulate policy and regulation to control energy consumption in the process of urbanization in order to achieve a long-term goal of sustainable development nationwide. The direct and total effects of urbanization on energy, coal and electricity consumption are significantly positive, whereas the indirect effects are insignificant. Energy control strategies should be continued in the era of new type urbanization, which emphasizes economic and intensive development. Urban sustainability prefers a compact city form, which favors high-density of population and economic activities but save energy used in transportation and construction due to shorter distance. The positive impact of urbanization on energy consumption indicates that the compact city strategy has not played effective and efficient roles in the past decades.

Fourth, the direct effects of urbanization and interaction terms in transportation and residential sectors demonstrate similarity in energy (coal, electricity) models. As for the total effects, results in agriculture and residential sectors demonstrate similarity in energy (coal, electricity) models. The direct effects of interaction terms for the six sectors in energy models are negative, whereas not significant in agriculture and construction sectors and positive in industry sector. It indicates that the effect of urbanization on energy consumption is revealed through three kinds of service sectors and the high-level urbanization reduces the contribution of sector energy consumption to the total energy consumption. It implies that the sectoral energy is controlled well or energy policy is better implemented in highly urbanized area, and suggests to deep urbanization in less urbanized area. The positive direct effect of interaction term between urbanization and industry implies that the direct effect of industry, as the largest energy demand sector, is released through industrialization and enhanced by urbanization. The strategies of sectoral development and management, such as agricultural modernization, industry structure upgrading, public transportation system, top-leader mechanism, and urban energy management system, should be strengthened. The direct effects of interaction term with industry is negative in electricity model, but positive in energy and coal model. The diversified direct effects of industry and transportation interaction term between energy, coal and electricity models indicate the different role of disaggregated energy between these sectors. The total effects of interaction terms are negative in all models, but with different significant level. Above all, the direct effect of urbanization is reflected and hindered by the development of service sectors at aggregate and disaggregated levels and show variations between sectors, and the agriculture and construction sector also works but not significant. To alleviate the impetus of urbanization on energy consumption, the development and utilization of clean and renewable energy is recommended urgently, especially in industry sector.

Finally, the indirect effects of urbanization are diversified between energy, coal and electricity models with interaction terms. In energy consumption models, the indirect effects of urbanization on energy consumption show significant results only in models with industry sector interaction. In coal models, the indirect effects of urbanization and interaction terms on coal consumption are significant in all sectors except retail. In electricity models, the indirect effects of urbanization on electricity consumption are significant in agriculture and industry sectors but with opposite signs. It should be noted that the direction, magnitude and transmission sectors of indirect effects are inconsistent between these energy categories. Such indirect effects of urbanization suggests a global stand of energy policy-making by considering the neighbor's sector consumption patterns and the entire process of urbanization.

This study has some limitations as well. The first limitation is related to the measurement of urbanization rate or level. Due to China's Hukou system, rural migrants living in urban areas are unable to benefit from local social welfare but contribute to the urbanization remarkably. It is still a debate on how to properly define urban area and urban people. And urbanization is a complicated process including not only migration but also urban expansion (Wang et al., 2015; Zhao and Chai, 2015; He et al., 2017). Second, the province level is not the most ideal spatial unit for modelling the impacts of urbanization on energy consumption as the consumptions are mainly concentrated in cities. New evidences from models developed by using the energy data sets for sectors at prefectural city level could be compared with those presented in this paper if these data sets could be available in the future. There is an urgent call for open data policy in China. Third, as only sectoral industrial data is considered in this paper, it is recommended to have a deep analysis at division or group or class level to support more detailed policy making at sub-level industrial classifications, especially the subdividing manufacturing sector.

Appendix

Table A1: Descriptive statistics

Variables (logarithm)	Mean	SD	Min	Median	Max
Energy consumption	8.898	0.836	5.966	8.962	10.569
Coal consumption	8.796	0.979	4.927	8.884	10.620
Electricity consumption	6.598	0.903	3.544	6.618	8.632
GDP	8.582	1.099	5.312	8.673	11.005
industrialization	3.621	0.251	2.477	3.684	3.971
tertiary	3.705	0.168	3.343	3.687	4.385
population	8.141	0.767	6.207	8.246	9.306
FDI	4.523	1.743	−0.587	4.833	7.448
Trade	6.812	1.769	2.187	6.671	10.887
eprice	4.862	0.252	4.459	4.886	5.613
estructure	0.210	1.011	−14.122	0.315	0.685
Urbanization	3.818	0.323	3.069	3.823	4.495
agriculture energy	4.941	0.891	2.062	5.170	6.512
agriculture coal	3.321	1.405	0.000	3.540	5.932
agriculture electricity	3.133	1.006	−0.136	3.123	5.276
industry energy	7.873	0.805	4.750	7.972	9.573
industry coal	7.169	0.956	3.628	7.401	9.016
industry electricity	6.399	0.949	2.811	6.428	8.594
transportation energy	6.062	0.957	2.727	6.132	8.092
transportation coal	2.788	1.271	0.000	2.779	6.244
transportation electricity	2.829	0.978	−0.410	2.882	4.906
construction energy	4.141	1.139	0.112	4.211	6.585
construction coal	2.283	1.245	0.000	2.468	5.711
construction electricity	2.448	0.913	0.000	2.450	4.372
retail energy	4.714	1.109	−1.032	4.834	6.986
retail coal	3.124	1.526	0.000	3.231	6.746
retail electricity	3.183	1.177	−1.032	3.245	5.943
resident energy	6.171	0.848	2.978	6.270	8.025
resident coal	4.958	1.418	0.000	5.268	7.249
resident electricity	4.597	1.073	1.098	4.697	7.013

Note: Variables which include 0 are added by 1 to take natural logarithm.

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