

Energy Consumption, Economic Growth and Energy Intensity in Guangdong of China (2006-2015)

Abstract This paper examines the effects of population, investment, urbanization, industrial structure, policy instrument and enterprise size on energy intensity in Guangdong, China. A dynamic optimal theoretical framework is utilized and empirical results are reported using panel data from 2006 to 2015. The fixed effects models and spatial fixed effects models both show that: (1) population, investment, urbanization and enterprise size decrease energy intensity, but industrial structure and policy instrument drive it up; (2) population, investment, urbanization and enterprise size increase the energy consumption and economic output, but industrial structure and policy instrument decrease them, China; (3) the spatial spillover effects are significant and should be considered in Guangdong, China.

Keywords Energy Intensity; Economic Performance; China; Spatial Panel

Econometrics

Running Head

Economic Growth; Energy; Spatial Econometrics

Recommendations for Resource Managers

(1) population, investment, urbanization and enterprise size decrease energy intensity, but industrial structure and policy instrument drive it up;

(2) population, investment, urbanization and enterprise size increase the energy consumption and economic output, but industrial structure and policy instrument decrease them, China;

(3) the spatial spillover effects are significant and should be considered in Guangdong, China.

1. Introduction

The objective of the paper is to examine population, investment, urbanization, industrial structure, policy instrument and enterprise size on energy intensity in Guangdong, China. Two econometric models are examined: Fixed Effects and Spatial Fixed Effects. So, we ask three questions: (1) How do population, investment, urbanization and enterprise size impact energy intensity? (2) Do industrial structure and policy instrument increase energy intensity? (3) How consistent and robust are the different econometric approaches in assessing the impacts from questions (1) and (2)?

To answer these questions, we provide a dynamic optimal theoretical framework and empirical evidence to show how population, investment, urbanization, industrial structure, policy instrument, and enterprise size affect energy intensity, energy consumption and economic output on a province level. The empirical results show that (1) population, investment, urbanization and enterprise size decrease energy intensity, but industrial structure and policy instrument drive it up; (2) population, investment, urbanization and enterprise size increase the energy consumption and economic output, but industrial structure and policy instrument decrease them, China; (3) the spatial spillover effects are significant and should be considered in Guangdong, China.

Actually, there is not many literature devoted to investigating the causal effects on energy intensity (Shahbaz et al. 2014). In terms of the study on the relationship between

energy consumption and urbanization, Liu (2009), Zhang and Lin (2012), Wang et al. (2014), Lin and Du (2015), and Wang et al. (2016) illustrate that urbanization increases energy consumption in China. On the other hand, the empirical research on the nexus between energy consumption and economic growth demonstrates in Table 1.

However, recently, the economists gradually transfer into the empirical research on energy intensity from the theoretical modeling. Hence, we would derive an energy consumption intensity model. According the literature above, the nexus between energy consumption and economic output has been extensively studied but the evidence so far is contradictory and inconclusive (Stern et al. 2018). Most of the scholars above just make good use of the national level data without any spatial factors, and there has been limited attention in economic literature devoted to investigating the effect of total income combining urbanization, industrial structure, and enterprise size on energy intensity in developing area. Comparing to the current studies, we try to set up a theoretical model to investigate the relationship between energy consumption, energy intensity and gross products (total income), and concentrate on using the data from the province level in Guangdong, China and consider the economic implication.

So, my contributions are following: (1) providing a new theoretical framework on the effects of population, investment, urbanization, industrial structure, policy instrument and enterprise size on energy intensity, and (2) designing fixed effect models integrated spatial factors to access the impacts on energy intensity, energy consumption, and economic output.

This introduction section provides a brief overview of prior research analyzing the energy intensity. These previous studies cover various sample periods and

geographical regions, and employ somewhat different theoretic models and empirical methodologies. In section 2, we outline the framework applying the optimal control theory with the general equilibrium structure in the determination of the energy intensity. In Section 3, we present the data and derive the econometric methods utilized in the empirical analysis from the theoretical framework. The impacts on energy intensity, energy consumption, and economic output are examined in section 4. Section 5 presents conclusions and further discussion.

2. Theoretic Framework

One objective is to derive a theoretical framework that connects urbanization and energy intensity and is based upon an optimal allocation that maximizes household's inter-temporal utility function (U). This inter-temporal model will be connected to energy consumption through investments in energy infrastructure, so the utilitarian inter-temporal utility function (W) can be expressed as below:

$$W = \sum_{t=0}^T U(C_t) \left(\frac{1}{1+\theta}\right)^t \quad (1)$$

where θ represents utility discount rate, C_t denotes numeraire consumption, over T number of years. We assume the utility function is iso-elastic form with a constant parameter γ :

$$U(C_t) = \frac{C_t^{1-\gamma}}{1-\gamma} \text{ for } \gamma > 0 \text{ and } \gamma \neq 1 \quad (2)$$

The optimization problem is expressed as below:

Under a constrained optimization format, we turn our attention to the constraints.

First is a constraint on the numeraire consumption is based on the income accounting identity:

$$Y_t = C_t + I_t + G_t \quad (3)$$

where I_t denotes all investment (private and public) that is outside the energy generation industry at year t and G_t denotes government investment on energy infrastructure at year t . Investment is the change in the economy's stock of capital:

$$I_t = K_{t+1} - (1 - \delta)K_t \quad (4)$$

Hence, plug (4) into (3), we obtain:

$$Y_t = C_t + G_t + K_{t+1} - K_t + \delta K_t \quad (5)$$

Writing this identity in discrete-time form we have $I_t = K_{t+1} - K_t = Y_t - C_t - G_t - \delta K_t$, where δ is the depreciation rate.

The constraint for numeraire consumption is: $C_t = Y_t - G_t - (K_{t+1} - K_t) - \delta K_t$. So, the change of capital stock can be derived from the (6) and (7):

$$K_{t+1} - K_t = Y_t - C_t - G_t - \delta K_t \quad (8)$$

The production function is assumed to be represented in Cobb-Douglas (C-D) form for each year t :

$$Y_t = Q(K_t, E_t, L_t) = K_t^a E_t^b L_t^d e^{v_t} \quad (9)$$

where K_t is capital, E_t is energy utilized in production, and L_t is labor. The parameters of equation (9) are restricted as: $0 < a < 1, 0 < b < 1, 0 < d < 1$ and $a + b + d = 1$.

The second constraint comes from the capacity of energy production due to available infrastructure. To do so, we use F_t to represent capacity of energy

infrastructure at year t . The capacity of energy infrastructure (F_{t+1}) at year $(t+1)$ is composed of annual investment on energy infrastructure (G_t) and the value of remaining stock of energy infrastructure. A convenient way of modeling the latter is to assume that the value of remaining stock of energy infrastructure at the end of year t is $(F_t - \pi F_t)$, where the depreciation rate is π . Therefore, we define value of changes in the capacity of energy infrastructure as

$$F_{t+1} = G_t + (F_t - \pi F_t) \quad (10)$$

Finally, the amount of energy consumption, E_t , is treated as an increasing functional of the capacity of energy infrastructure and other factors (ε_t) so that $E_t = fF_t\varepsilon_t$, where f is the transfer coefficient representing how many percentage of energy stock can be effectively used. Therefore, we have the following set-up for an optimal control problem:

$$\text{Max}_{C_t, G_t} \sum_{t=0}^T U(C_t) \left(\frac{1}{1+\theta}\right)^t$$

$$\text{s.t. } K_{t+1} - K_t = K_t^a (f\varepsilon_t F_t)^b L_t^d - C_t - G_t - \delta K_t$$

$$F_{t+1} = G_t + (F_t - \pi F_t)$$

$$K_0 = K^* \text{ and } K_T \text{ is free}$$

$$F_0 = F^* \text{ and } F_T \text{ is free}$$

$$G_t \geq 0, F_t \geq 0, K_t \geq 0 \text{ and } L_t \geq 0$$

Hence, we form the current Hamiltonian Function:

$$\mathcal{H}_C = \frac{C_t^{1-\gamma}}{1-\gamma} + \left(\frac{1}{1+\theta}\right)\varphi_{t+1}[K_t^a(\varepsilon_t f F_t)^b L_t^d - C_t - G_t - \delta K_t] + \left(\frac{1}{1+\theta}\right)\tau_{t+1}(G_t - \pi F_t)$$

The first order conditions are as below:

$$\frac{\partial \mathcal{H}_C}{\partial G_t} = -\left(\frac{1}{1+\theta}\right)\varphi_{t+1} + \left(\frac{1}{1+\theta}\right)\tau_{t+1} = 0 \quad (11)$$

$$\frac{\partial \mathcal{H}_C}{\partial F_t} = \left(\frac{1}{1+\theta}\right)\varphi_{t+1} b A_t K_t^a (f \varepsilon_t)^b F_t^{b-1} L_t^d - \left(\frac{1}{1+\theta}\right)\tau_{t+1} \pi = -\left[\left(\frac{1}{1+\theta}\right)\tau_{t+1} - \tau_t\right] \quad (12)$$

$$\frac{\partial \mathcal{H}_C}{\partial K_t} = \left(\frac{1}{1+\theta}\right)\varphi_{t+1}[a A_t K_t^{a-1} (f \varepsilon_t F_t)^b L_t^d - \delta] = -\left[\left(\frac{1}{1+\theta}\right)\varphi_{t+1} - \varphi_t\right] \quad (13)$$

The solutions of the optimal control model above is as follow

$$\varphi_{t+1} = \tau_{t+1} \quad (14)$$

$$F_t = \frac{\left(\frac{1}{1+\theta}\right)\varphi_{t+1} b}{\left(\frac{1}{1+\theta}\right)\varphi_{t+1}(\pi - 1) + \varphi_t} Y_t \quad (15)$$

$$\varphi_t = \left(\frac{1+\theta}{1+\theta-\delta}\right)e^t \quad (16)$$

Plug (14) and (16) into (15), we obtain:

$$F_t = \frac{b}{\pi + \theta - \delta} Y_t \quad (19)$$

According to the transfer relationship between energy capacity and energy consumption

$E_t = f \varepsilon_t F_t$, we obtain the optimal energy consumption function

$$E_t = \frac{b f \varepsilon_t}{\pi + \theta - \delta} Y_t \quad (20)$$

If we let $\beta = \frac{b f \varepsilon_t}{\pi + \theta - \delta}$, then the energy consumption function can be expressed

as: $E_t = \beta Y_t$. Therefore, there should be a parameter β satisfies that

$$\ln E_t = \ln \left[\left(\frac{bf \varepsilon_t}{\pi + \theta - \delta} \right) Y_t \right] + \ln \varepsilon_t = B \ln Y_t + \ln \varepsilon_t \quad (21)$$

In terms of (9), we can obtain: $\ln Y_t = a \ln K_t + b \ln E_t + d \ln L_t + v_t$ (22)

So, if we plug (22) into (21), we obtain:

$$\begin{aligned} \ln E_t &= B(a \ln K_t + b \ln E_t + d \ln L_t + v_t) + \ln \varepsilon_t \\ &= Ba \ln K_t + Bb \ln E_t + Bd \ln L_t + Bv_t + \ln \varepsilon_t \end{aligned}$$

Therefore,

$$\ln E_t = \frac{Ba}{1 - Ba} \ln K_t + \frac{Bd}{1 - Ba} \ln L_t + \frac{Bv_t + \ln \varepsilon_t}{1 - Ba} \quad (23)$$

Furthermore, let (23) minus (22), we obtain:

$$\begin{aligned} \ln \left(\frac{E_t}{Y_t} \right) &= \frac{Ba - a + Baa}{(1 - Ba)(1 + b)} \ln K_t + \frac{Bd - d + Bad}{(1 - Ba)(1 + b)} \ln L_t \\ &\quad + \frac{Bv_t + \ln \varepsilon_t - v_t + Bav_t}{(1 - Ba)(1 + b)} \quad (24) \end{aligned}$$

Finally, we plug (23) into (22), then get:

$$\ln Y_t = \left(a + \frac{bBa}{1 - Ba} \right) \ln K_t + \left(\frac{bBd}{1 - Ba} + Bd \right) \ln L_t + \left(\frac{Bv_t + \ln \varepsilon_t}{1 - Ba} + \ln \varepsilon_t \right) \quad (25)$$

3. Econometric Methodology and Data

3.1 Econometric Methodology

In order to estimate the coefficients in equation (23), (24) and (25) and capture the fixed effects on city and time, I extend equation (23) and get:

$$\ln E_{it} = A_0 + \alpha_i + \mu_t + \beta X'_{it} + \frac{Ba}{1 - Ba} \ln K_t + \frac{Bd}{1 - Ba} \ln L_t + e_{it} \quad (26)$$

where $A_0 + \alpha_i + \mu_t + \beta X'_{it} + e_{it} = \frac{Bv_{it} + \ln \varepsilon_{it}}{1 - Ba}$. X'_{it} is the covariate vector, α_i captures all unobserved, time-constant factors that affect $\ln Y_{it}$, which is individual fixed effect. The year effect, μ_t , is also treated as a parameter to be estimated. u_{it} is the perturbation term varying with the city and year. And then we also get the extension

form from (24):

$$\ln\left(\frac{E_{it}}{Y_{it}}\right) = A_0 + \alpha_i + \mu_t + \beta X'_{it} + \frac{Ba - a + Baa}{(1 - Ba)(1 + b)} \ln K_{it} + \frac{Bd - d + Bad}{(1 - Ba)(1 + b)} \ln L_{it} + \epsilon_{it} \quad (27)$$

where $A_0 + \alpha_i + \mu_t + \beta X'_{it} + \epsilon_{it} = \frac{Bv_{it} + \ln \epsilon_{it} - v_{it} + Bav_{it}}{(1 - Ba)(1 + b)}$. Similarly, we extend

(25) into the following form:

$$\ln Y_{it} = A_0 + \alpha_i + \mu_t + \beta X'_{it} + \left(a + \frac{bBa}{1 - Ba}\right) \ln K_{it} + \left(\frac{bBd}{1 - Ba} + Bd\right) \ln L_{it} + u_{it} \quad (28)$$

where $A_0 + \alpha_i + \mu_t + \beta X'_{it} + u_{it} = \left(\frac{Bv_{it} + \ln \epsilon_{it}}{1 - Ba} + \ln \epsilon_{it}\right)$.

Furthermore, if we measure the spatial spillover effect, the equation (26) can be extended into the Spatial Fixed Effects Model:

$$\ln E_{it} = A_0 + \alpha_i + \mu_t + \beta X'_{it} + \frac{Ba}{1 - Ba} \ln K_t + \frac{Bd}{1 - Ba} \ln L_t + \rho w'_i \ln E_{it} + \epsilon_{it} \quad (29)$$

where $\rho w'_i \ln E_{it} + \epsilon_{it} = e_{it}$, ϵ_{it} is the residual for (29) and w'_i is the i th row of the

spatial weight matrix $W = \begin{bmatrix} w_{11} & \cdots & w_{1n} \\ \vdots & & \vdots \\ w_{n1} & \cdots & w_{nn} \end{bmatrix}$. The coefficient of spatial

autoregressive $\rho \neq 0$ is an unknown parameter which specifies the strength of

correlation between co-located provinces. Error term ϵ_{it} represents unobservable

factors excluding spatial spillover effects. In terms of W , if city i and city j have a

common border, then $w_{ij} = 1$, otherwise $w_{ij} = 0$. And the diagonal elements are 0,

that is, $w_{11} = \cdots = w_{nn} = 0$, which means that the distance between the same city is

0.

Similarly, the spatial fixed effects forms of (27) and (28) are as below,

respectively:

$$\ln\left(\frac{E_{it}}{Y_{it}}\right) = A_0 + \alpha_i + \mu_t + \beta X'_{it} + \frac{Ba - a + Baa}{(1 - Ba)(1 + b)} \ln K_{it} + \frac{Bd - d + Bad}{(1 - Ba)(1 + b)} \ln L_{it} \\ + \rho w'_i \ln\left(\frac{E_{it}}{Y_{it}}\right) + \vartheta_{it} \quad (30)$$

where $\rho w'_i \ln\left(\frac{E_{it}}{Y_{it}}\right) + \vartheta_{it} = \epsilon_{it}$.

$$\ln Y_{it} = A_0 + \alpha_i + \mu_t + \beta X'_{it} + \left(a + \frac{bBa}{1 - Ba}\right) \ln K_{it} + \left(\frac{bBd}{1 - Ba} + Bd\right) \ln L_{it} \\ + \rho w'_i \ln Y_{it} + \mu_{it} \quad (31)$$

where $\rho w'_i \ln Y_{it} + \mu_{it} = u_{it}$

3.2 Data and Description Statistics

In order to get the estimations from (26) to (31), we collect the panel data of 21 cities in Guangdong, China (See Figure 1) from 2006 to 2015, which are all from the statistical yearbook of Guangdong (2007-2016).

Table 2 and 3 present the variables, their respective definitions, and summary statistics. Figure 2 and 3 show the spatial distribution maps of Guangdong Province about GDP and energy consumption in 2015, respectively.

4 Empirical Results

The Hausman test is performed before the regression in Table 5.

Table 5 shows that the p-values of accept the null hypothesis of random effects are less than 0.1, so the fixed effects models should be selected.

Table 5 shows when energy intensity is dependent variable, the coefficient of urbanization is significantly negative, which is consistent with the empirical results from Al-Mulali et al. (2013) and Shahbaz et al. (2015). Besides, population and investment are also significantly and negatively associated with energy intensity. This result is different from the finding of Li and Lin (2015). The proportion of primary

industry and secondary industry are significantly positively correlated with energy intensity, while the effect of the eleventh five-year plan on energy intensity is significantly positive.

However, the coefficients in other two regressions are significantly opposite with those in the first regression, but the impacts of *sl* and *hl* on GDP and energy consumption are significantly positive, which is nonsignificant.

3.4 Extension: Spatial Econometric Analysis

In this section, we consider the spatial spillover effect. Figure 4 and 5 show the Moran Scatter Plots of GDP and energy consumption.

The GDP Moran Index map of Guangdong in Figure 4 and energy consumption Moran Index map of Guangdong in Figure 5 also show the regional non-equilibrium distribution of Guangdong province in 2015, and most of the resources are agglomerated in the middle of Guangdong, where is the Pearl River Delta area.

Table 6 illustrates that the empirical results are consistent with the results from Table 5. However, the absolute values of the coefficients across the three regressions are significantly less than those in the Fixed Effects Models, which means the Fixed Effects Models overestimate the impact of covariate variables. Especially, the coefficients of spatial autoregressive items across these three models are significantly positive. It means that the spatial spillover effects are obvious and should be considered.

In terms of the variable *sl*, after considering spatial dependence, the effect of it on energy intensity becomes significantly negative, which is the same with the conclusion from Salim and Shafiei (2014) and Ren et al. (2015).

5. Conclusions and Further Discussion

Energy consumption and energy intensity are vitally important for a developing region. In this paper, we provide a framework to conduct theoretical and empirical research demonstrating how population, investment, urbanization, industrial structure, and enterprise size affect energy intensity, energy consumption and economic performance by setting up the dynamic optimization models and design the fixed effects models and spatial fixed effects models using panel dataset from Guangdong, China.

Based on the theoretical framework, the empirical results demonstrate three findings: (1) population, investment, urbanization and enterprise size decrease energy intensity, but industrial structure and policy instrument drive it up; (2) population, investment, urbanization and enterprise size increase the energy consumption and economic output, but industrial structure and policy instrument decrease them, China; and (3) the spatial spillover effects are significant and should be considered in Guangdong, China.

Finally, this study has limitations that include: (1) the theoretical model assumes utility optimization and general equilibrium, (2) the specification of econometric model does not consider macroeconomic factors such as interest rates, and (3) important uncertainties referring to the export and import between cities, energy market structures, and decarbonizing technology are not included in the empirical models.

Recommendations for Resource Managers

(1) population, investment, urbanization and enterprise size decrease energy intensity, but industrial structure and policy instrument drive it up;

(2) population, investment, urbanization and enterprise size increase the energy consumption and economic output, but industrial structure and policy instrument decrease them, China;

(3) the spatial spillover effects are significant and should be considered in Guangdong, China.

Acknowledgment

This work was supported by the Key Project of National Natural Science Foundation in China [71742003]; National Ten Thousand Outstanding Young Scholar Program [W02070352].

Author Contributions

Yiming He: Introduction, Theoretical Framework, Data and Econometric Methodology, Conclusion and further discussion;

Heyuan Huang: Empirical Results

References

- Al-Mulali, Usama, Hassan Gholipour Fereidouni, Janice Y M Lee, and Che Normee Binti Che Sab. 2013. "Exploring the Relationship between Urbanization, Energy Consumption, and CO2 Emission in MENA Countries." *Renewable and Sustainable Energy Reviews* 23: 107–12.
- Angrist J. D. and J. S. Pischke. 2008. Massachusetts Institute of Technology and The London school of Economics *Mostly Harmless Econometrics : An Empiricist 's Companion*.
- Balcilar, Mehmet, Zeynel Abidin Ozdemir, and Yalcin Arslanturk. 2010. "Economic Growth and Energy Consumption Causal Nexus Viewed through a Bootstrap Rolling Window." *Energy Economics* 32(6): 1398–1410.
- Bloch, Harry, Shuddhasattwa Rafiq, and Ruhul Salim. 2015. "Economic Growth with Coal, Oil and Renewable Energy Consumption in China: Prospects for Fuel Substitution."

- Economic Modelling* 44: 104–15.
- Dergiades, Theologos, Georgios Martinopoulos, and Lefteris Tsoulfidis. 2013. “Energy Consumption and Economic Growth: Parametric and Non-Parametric Causality Testing for the Case of Greece.” *Energy Economics* 36: 686–97.
- Dhungel, Kamal Raj. 2014. “On the Relationship between Electricity Consumption and Selected Macroeconomic Variables : Empirical Evidence from Nepal.” *Modern Economy* (April): 360–66.
- Du, Zhipeng, and Yiming He. 2017. “Nexus between Energy Consumption and Economic Performance in China.” *Journal of Business and Economics* 8(9): 1292–1305.
- Fuinhas, Jose Alberto, and Antonio Cardoso Marques. 2012. “Energy Consumption and Economic Growth Nexus in Portugal, Italy, Greece, Spain and Turkey: An ARDL Bounds Test Approach (1965-2009).” *Energy Economics* 34(2): 511–17.
- Gao, Shaohui, and Yiming He. 2017. “The Effect of Urbanization and Economic Performance on Metropolitan Water Consumption : Theoretic Model and Evidence from Guangzhou of China.” *Applied Economics and Finance* 4(2): 163–71.
- He, Yiming, and Shaohui Gao. 2017. “Gas Consumption and Metropolitan Economic Performance : Models and Empirical Studies from Guangzhou , China.” *International Journal of Energy Economics and Policy* 7(2): 121–26.
- Herrerias, M. J., R. Joyeux, and E. Girardin. 2013. “Short- and Long-Run Causality between Energy Consumption and Economic Growth: Evidence across Regions in China.” *Applied Energy* 112: 1483–92.
- Jakovac, Pavle. 2013. “Empirical Analysis on Economic Growth and Energy Consumption Relationship in Croatia.” *Economic Research-Ekonomska Istraživanja* 26(4): 21–42.
- Kasperowicz, R. 2014. “Economic Growth and Energy Consumption in 12 European Countries: A Panel Data Approach.” *Journal of International Studies* 7(3): 112–22.
- Kwakwa, Paul Adjei. 2012. “Disaggregated Energy Consumption and Economic Growth in Ghana.” *International Journal of Energy Economics and Policy* 2(1): 34–40.
- Li, Ke, and Boqiang Lin. 2015. “Impacts of Urbanization and Industrialization on Energy Consumption/CO₂ Emissions: Does the Level of Development Matter?” *Renewable and Sustainable Energy Reviews* 52: 1107–22.
- Liddle, Brantley, and Sidney Lung. 2014. “Might Electricity Consumption Cause Urbanization Instead? Evidence from Heterogeneous Panel Long-Run Causality Tests.” *Global Environmental Change* 24(1): 42–51.
- Lin, Boqiang, and Zhili Du. 2015. “How China’s Urbanization Impacts Transport Energy Consumption in the Face of Income Disparity.” *Renewable and Sustainable Energy Reviews* 52: 1693–1701.
- Lin, Boqiang, and Mohamed Moubarak. 2014. “Renewable Energy Consumption - Economic Growth Nexus for China.” *Renewable and Sustainable Energy Reviews* 40: 111–17.
- Liu, Yaobin. 2009. “Exploring the Relationship between Urbanization and Energy Consumption in China Using ARDL (Autoregressive Distributed Lag) and FDM (Factor Decomposition Model).” *Energy* 34(11): 1846–54.
- Muftaudeen, Olarinde, and Joseph Ayoola Omojolaibi. 2014. “Electricity Consumption , Institutions and Economic Growth in Nigeria : What Does Evidence Say So Far ?” *Journal of Economics and Sustainable Development* 5(12): 40–56.

- Ocal, Oguz, and Alper Aslan. 2013. "Renewable Energy Consumption-Economic Growth Nexus in Turkey." *Renewable and Sustainable Energy Reviews* 28: 494–99.
- Odhambo, Nicholas M. 2009. "Energy Consumption and Economic Growth Nexus in Tanzania: An ARDL Bounds Testing Approach." *Energy Policy* 37(2): 617–22.
- Pao, Hsiao Tien, and Hsin Chia Fu. 2013. "Renewable Energy, Non-Renewable Energy and Economic Growth in Brazil." *Renewable and Sustainable Energy Reviews* 25: 381–92.
- Qazi, Muhammad Adnan Hye, and Sana Riaz. 2008. "Causality between Energy Consumption and Economic Growth : The Case of Pakistan." *The Lahore Journal of Economics* 2(Winter): 45–58.
- Ren, Lijun, Wenjun Wang, Jianchun Wang, and Rutao Liu. 2015. "Analysis of Energy Consumption and Carbon Emission during the Urbanization of Shandong Province, China." *Journal of Cleaner Production* 103: 534–41.
- Salim, Ruhul A., and Sahar Shafiei. 2014. "Urbanization and Renewable and Non-Renewable Energy Consumption in OECD Countries: An Empirical Analysis." *Economic Modelling* 38: 581–91.
- Shahbaz, Muhammad, Saleheen Khan, and Mohammad Iqbal Tahir. 2013. "The Dynamic Links between Energy Consumption, Economic Growth, Financial Development and Trade in China: Fresh Evidence from Multivariate Framework Analysis." *Energy Economics* 40: 8–21.
- Shahbaz, Muhammad, Nanthakumar Loganathan, Rashid Sbia, and Talat Afza. 2015. "The Effect of Urbanization, Affluence and Trade Openness on Energy Consumption: A Time Series Analysis in Malaysia." *Renewable and Sustainable Energy Reviews* 47: 683–93.
- Shahbaz, Muhammad, Rashid Sbia, Helmi Hamdi, and Ilhan Ozturk. 2014. "Economic Growth, Electricity Consumption, Urbanization and Environmental Degradation Relationship in United Arab Emirates." *Ecological Indicators* 45: 622–31.
- Solarin, Sakiru Adebola, and Muhammad Shahbaz. 2013. "Trivariate Causality between Economic Growth, Urbanisation and Electricity Consumption in Angola: Cointegration and Causality Analysis." *Energy Policy* 60: 876–84.
- Tugcu, Can Tansel, Ilhan Ozturk, and Alper Aslan. 2012. "Renewable and Non-Renewable Energy Consumption and Economic Growth Relationship Revisited: Evidence from G7 Countries." *Energy Economics* 34(6): 1942–50.
- Wang, Qiang, Shi Dai Wu, Yue E. Zeng, and Bo Wei Wu. 2016. "Exploring the Relationship between Urbanization, Energy Consumption, and CO2 Emissions in Different Provinces of China." *Renewable and Sustainable Energy Reviews* 54: 1563–79.
- Wang, Shaojian et al. 2014. "Urbanisation, Energy Consumption, and Carbon Dioxide Emissions in China: A Panel Data Analysis of China's Provinces." *Applied Energy* 136: 738–49.
- Wang, Yuan et al. 2011. "Energy Consumption and Economic Growth in China: A Multivariate Causality Test." *Energy Policy* 39(7): 4399–4406.
- Yang, Xiaokai, and Yew Kwang Ng. 1995. "Theory of the Firm and Structure of Residual Rights." *Journal of Economic Behavior and Organization* 26(1): 107–28.
- Yildirim, Ertugrul, and Alper Aslan. 2012. "Energy Consumption and Economic Growth Nexus for 17 Highly Developed OECD Countries: Further Evidence Based on Bootstrap-Corrected Causality Tests." *Energy Policy* 51: 985–93.

- Yildirim, Ertuğrul, Şenay Saraç, and Alper Aslan. 2012. “Energy Consumption and Economic Growth in the USA: Evidence from Renewable Energy.” *Renewable and Sustainable Energy Reviews* 16: 6770–74.
- Yuan, Jia Hai, Jian Gang Kang, Chang Hong Zhao, and Zhao Guang Hu. 2008. “Energy Consumption and Economic Growth: Evidence from China at Both Aggregated and Disaggregated Levels.” *Energy Economics* 30(6): 3077–94.
- Zhang, Chuanguo, and Yan Lin. 2012. “Panel Estimation for Urbanization, Energy Consumption and CO₂ Emissions: A Regional Analysis in China.” *Energy Policy* 49: 488–98.
- Zhang, Yue-Jun. 2011. “Interpreting the Dynamic Nexus between Energy Consumption and Economic Growth: Empirical Evidence from Russia.” *Energy Policy* 39(5): 2265–72.
- Zhao, Yabo, and Shaojian Wang. 2015. “The Relationship between Urbanization, Economic Growth and Energy Consumption in China: An Econometric Perspective Analysis.” *Sustainability* 7(5): 5609–27.

Table 1 Summary of recent literature review for energy consumption and economic growth

Authors	Methodology	Time Period	Region / Country	Confirmed hypothesis
Balcilar et al., (2010)	bootstrap granger non-causality	1960- 2006	G-7 countries	growth, neutrality
Fuinhas and Marques (2012)	autoregressive distributed lag bounds test	1965 - 2009	Portugal,Italy,Greece,Spain and Turkey	feedback
Tugcu et al., (2012)	autoregressive distributed lag and causality analysis	1980–2009	G7 countries	growth, feedback
Dergiades et al., (2013)	Granger causality test and non-linear causality testing	1960–2008	Greece	growth,
Bloch et al., (2015)	autoregressive distributed lag and vector error correction modeling	1977 - 2013 and 1965 - 2011	China	feedback
Odhambo (2009)	autoregressive distributed lag bounds testing approach and Granger causality	1971–2006	Tanzania	growth
Zhang (2011)	Granger causality	1970- 2008	Russia	feedback
Wang et al. (2011)	autoregressive distributed lag bounds testing approach and Granger causality	1972- 2006	China	growth
Yildirim and Aslan(2012)	the bootstrap-corrected causality test	1964- 2009	OECD countries	growth, feedback, and neutrality
Herrerias et al.,(2013)	panel cointegration techniques	1999- 2009	China	conservation
Ertuğrul et al.,(2012)	Toda–Yamamoto procedure and bootstrap-corrected causality test	1949- 2010	USA	neutrality
Ocal and Aslan(2013)	autoregressive distributed lag approach and the Toda–Yamamoto causality tests	1990- 2010	Turkey	neutrality
Lin and Moubarak(2014)	Autoregressive Distributed Lag approach to cointegration and Johansen cointegration	1977–2011	China	feedback
Qazi and Riaz (2008)	autoregressive distributed lag bounds-testing approach to cointegration and the Granger causality test	1971- 2007	Pakistan	conservation
Kwakwa (2012)	Johansen cointegration test and granger causality test	1971- 2007	Ghana	conservation
Muftaudeen and Omojolaibi (2014)	Granger causality test	1980- 2011	Nigeria	neutrality

Jakovac (2013)	Granger causality test	1952- 2010	Croatia	feedback
Dhungel (2014)	Johansen cointegration test and Error Correction Model	1974- 2011	Nepal	conservation
Shahbaz et al., (2013)	autoregressive distributed lag bounds testing and Granger causality	1971- 2011	China	growth
Yuan et al. (2008)	Johansen cointegration and Granger causality	1963- 2005	China	conversation
Pao and Fu(2013)	cointegration test and Granger causality	1980- 2010	Brazil	growth, feedback and conversation
Zhao and Wang (2015)	Granger causality	1980–2012	China	feedback
Kasperowicz (2014)	panel least squares method	2000- 2012	12 European countries	growth
He and Gao (2017)	Johansen cointegration, autoregressive distributed lag bounds testing and Granger causality	1978- 2013	China	conversation
Du and He (2017)	Johansen cointegration, autoregressive distributed lag bounds testing and Granger causality	1983- 2014	China	growth and neutrality

Table 2 Variable Definitions

Variable	Mnemonic	Definition
energy intensity	ln_ecupgdp	Natural logarithm of energy consumption over GDP
GDP	ln_gdp	Natural logarithm of GDP
Total energy consumption	ln_ecutgdp	Natural logarithm of total energy consumption
Working population	ln_nep	Natural logarithm of the total number of employed
Urbanization	utop	urban population over total population
FAI	ln_fai	Natural logarithm of fixed asset investment
Primary industry proportion	fi	Primary industry output value over GDP
Secondary industry proportion	si	Ratio of secondary industry output value to GDP
Small scale enterprise proportion	sl	The number of small scale enterprise over the total number of enterprise
Medium scale enterprise proportion	ml	The number of medium scale enterprise over the total number of enterprise
Heavy industry proportion	hl	The number of heavy industry enterprise over the total number of secondary industry enterprise
Policy	_eleven	Whether it is in the eleventh five-year plan period (Dummy variable)

Table 3 Descriptive statistics

Variable	Obs #	Mean	Variance	Minimum	Maximum	Kurtosis	Skewness
ln_ecupgdp	210	-0.23498	0.359921	-0.88829	0.71183	0.0211	0.0034
ln_gdp	210	7.232889	0.995362	5.497983	9.80369	0.9683	0.0001
ln_ecutgdp	210	6.997913	0.859516	4.94977	9.09486	0.8554	0.0089
utop	210	61.1629	20.25278	34.35	100	0	0.0023
ln_nep	210	5.447518	0.565075	4.550714	6.80919	0.4531	0.0001
ln_fai	210	6.314447	0.880346	4.629472	8.59526	0.0407	0.1865
fi	210	11.08857	8.17529	0	33.6	0	0.0412
si	210	48.56762	7.905428	29	65.6	0	0.9296
sl	210	0.377046	0.146086	0.066748	0.70137	0	0.0914
ml	210	0.337733	0.097466	0.084107	0.57872	0.8869	0.8638
hl	210	0.588398	0.145572	0.281279	0.8543	0	0.2994
_eleven	210	0.5	0.501195	0	1	-	1

Table 4 Hausman test result of Fixed Effect Model

Independent variable	Chi2	Prob>chi2
ln_ecupgdp	15.57	0.0764
ln_gdp	154.65	0.0000
ln_ecutgdp	26.82	0.0015

Table 5 Results of Fixed Effects Models

VARIABLES	ln_ecupgdp	ln_gdp	ln_ecutgdp
utop	-0.00380*** (0.00103)	0.0100*** (-0.00263)	0.00622*** (-0.00225)
ln_nep	-0.156*** (0.0401)	0.354*** (-0.103)	0.198** (-0.0878)
ln_fai	-0.137*** (0.00981)	0.426*** (0.0251)	0.289*** (0.0215)
fi	0.00374** (0.00189)	-0.0160*** (0.00483)	-0.0123*** (0.00413)
si	0.00604*** (0.00106)	-0.00509* (0.00272)	0.000954 (0.00233)
sl	0.0191 (0.0377)	-0.247** (0.0966)	-0.228*** (0.0825)
ml	0.0225 (0.0558)	-0.146 (0.143)	-0.123 (0.122)
hl	-0.0593 (0.0748)	0.399** (0.192)	0.340** (0.164)
_leleven_1	0.0565*** (0.0107)	-0.170*** (0.0273)	-0.114*** (0.0233)
Constant	1.372*** (0.265)	2.416*** (0.680)	3.789*** (0.581)
Observations	210	210	210
R-squared	0.917	0.940	0.909
Number of id	21	21	21

Note: *** p<0.01, ** p<0.05, * p<0.1

Table 6 Results of Spatial Fixed Effects Models

VARIABLES	ln_ecupgdp	ln_gdp	ln_ecutgdp
utop	-0.00214*** (0.000609)	0.00628*** (0.00160)	0.00470*** (0.00171)
ln_nep	-0.0574** (-0.0241)	0.118* (-0.0686)	0.128* (0.0741)
ln_fai	-0.0332*** (0.00826)	0.172*** (0.0228)	0.173*** (0.0220)
fi	7.41e-05 (0.00114)	-0.00610** (0.00304)	-0.00761** (0.00330)
si	0.00120* (0.000688)	0.00496*** (0.00178)	0.00522*** (0.00190)
sl	-0.0387* (0.0227)	-0.155*** (0.0598)	-0.200*** (0.0658)
ml	0.0109 (0.0331)	-0.0445 (0.0878)	-0.0463 (0.0971)
hl	0.0368 (0.0446)	0.334*** (0.117)	0.378*** (0.129)
_leleven_1	0.0218*** (0.00663)	-0.641*** (0.0426)	-0.468*** (0.0549)
Spatial _rho	0.713*** (0.0405)	0.838*** (0.0246)	0.698*** (0.0392)
Variance_ lgt_theta	-3.835*** (0.169)	-3.366*** (0.192)	-3.136*** (0.190)
Variance_ sigma2_e	0.000431*** (4.39e-05)	0.00334*** (0.000368)	0.00411*** (0.000441)
Constant	0.475*** (0.178)	0.182 (0.446)	1.327** (0.517)
Observations	210	210	210
R-squared	0.216	0.438	0.372
Number of id	21	21	21

Note: (1)Standard errors in parentheses; (2)*** p<0.01, ** p<0.05, * p<0.1



Figure 1. Map of Canton of China

Source: Code in R by Authors

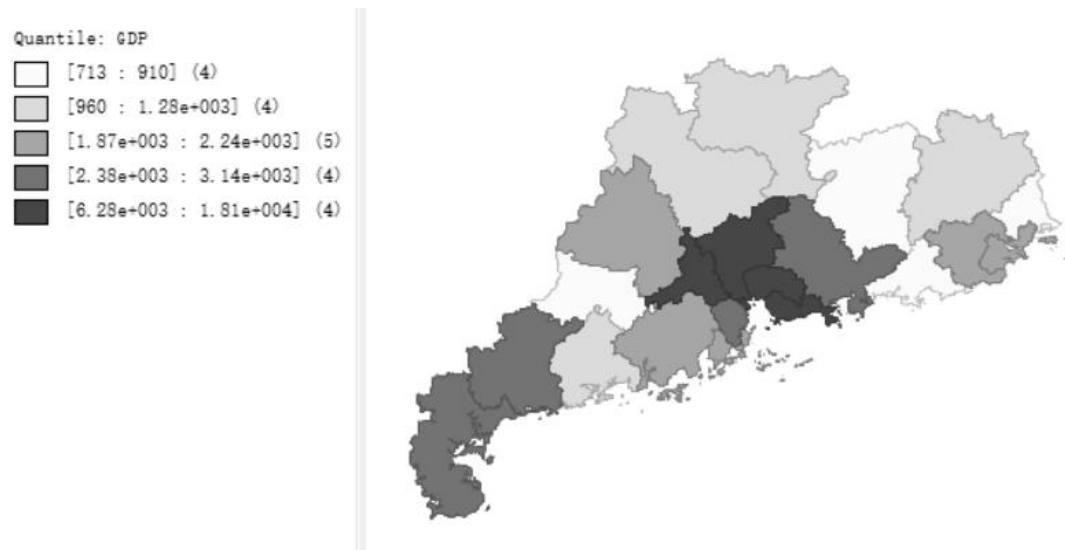


Figure2. 2015 GDP Spatial Distribution Map of Guangdong

Source: Code in Geoda by Authors

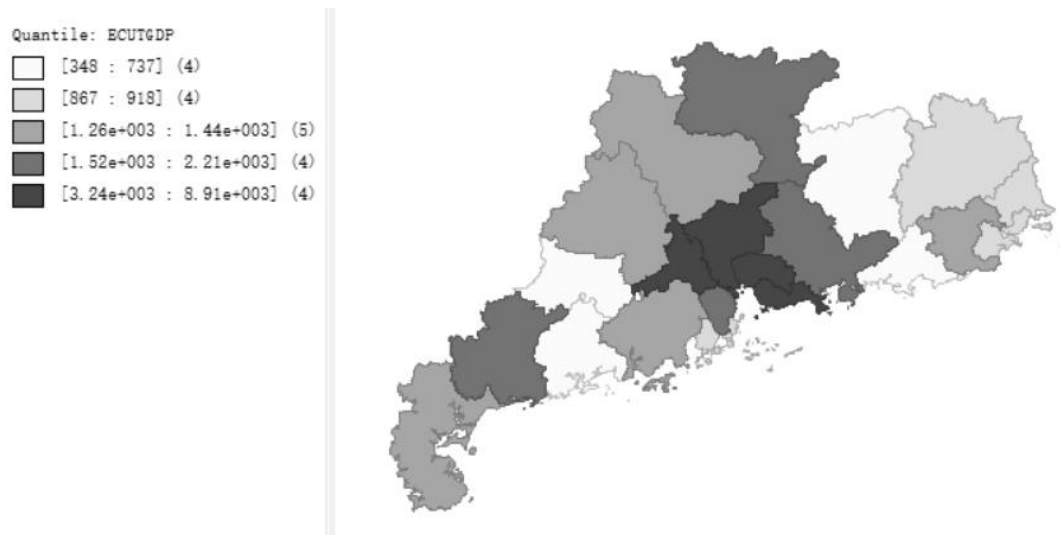
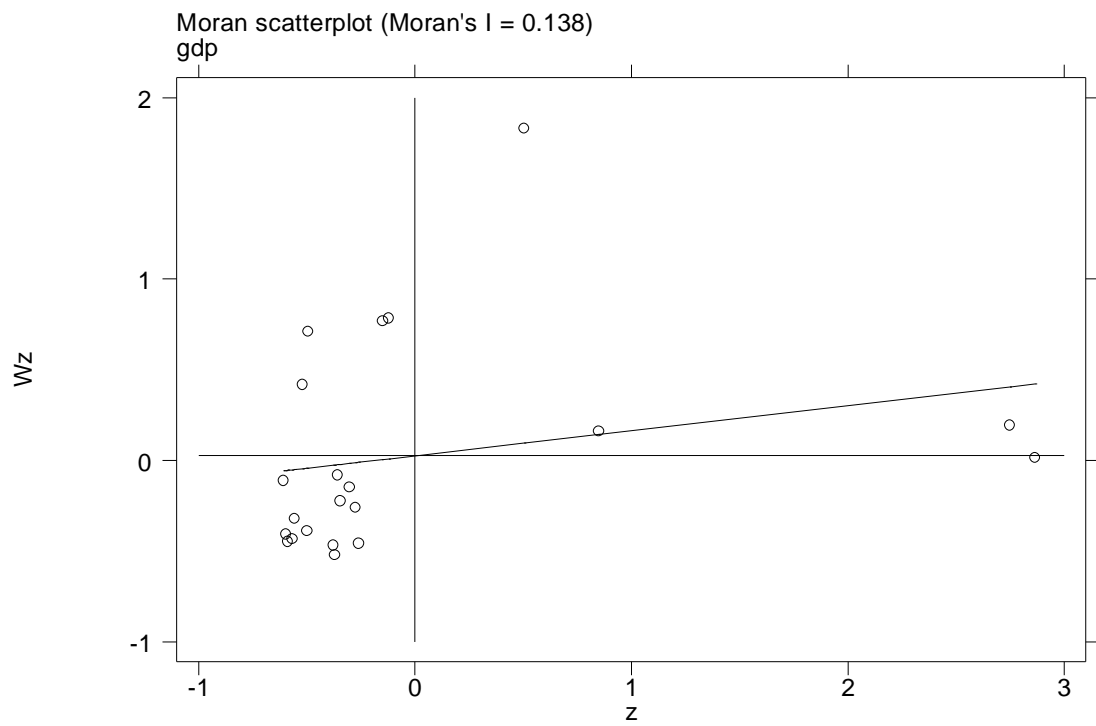


Figure3. 2015 Energy Consumption Spatial Distribution Map of Guangdong

Source: Code in Geoda by Authors



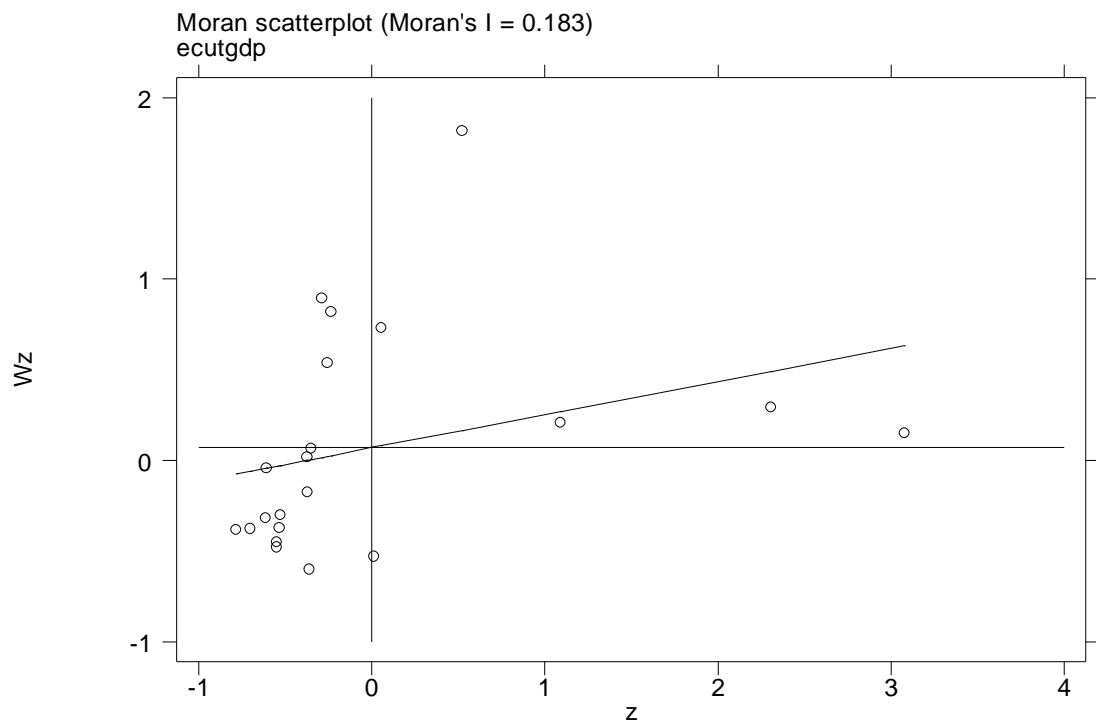


Figure 5. 2015 Energy Consumption of Moran Scatter Plot of Guangdong

Source: Code in Geoda by Authors

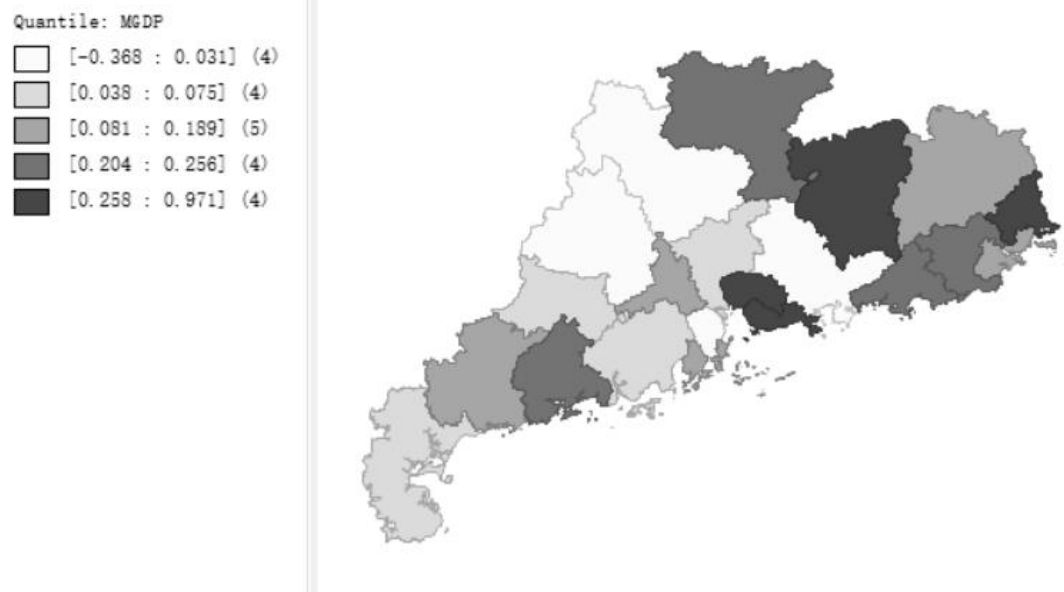


Figure 6. 2015 GDP of Moran Index Map of Guangdong

Source: Code in Geoda by Authors

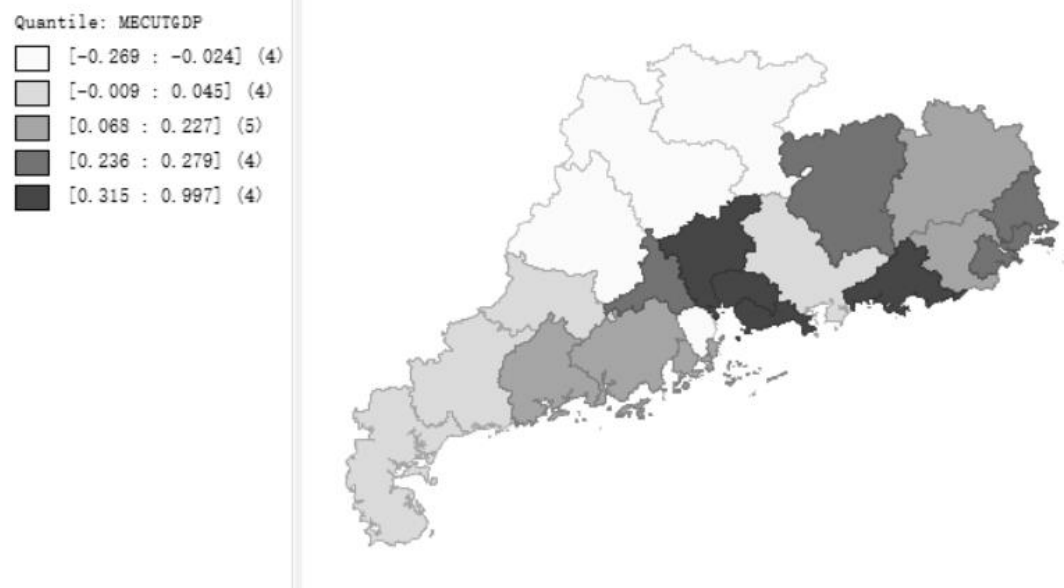


Figure 7. 2015 Energy Consumption of Moran Index Map of Guangdong

Source: Code in Geoda by Authors