Energy Intensity in Guangdong of China

Forthcoming in Natural Resource Modeling

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Abstract This paper investigates 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 energy intensity has significant spatial spillover effect that 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 energy intensity has significant spatial spillover effect that should be considered in Guangdong, China.

1. Introduction

In order 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. The regressions show that (1) urbanization, investment, population, 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 energy intensity has significant spatial spillover effect that 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). However, Liu (2009), Zhang and Lin (2012), illustrate urbanization increases energy consumption in China. However, recently, the economists gradually transfer into the empirical research on energy intensity from the theoretical modeling (Table 1). Hence, we would derive an energy consumption intensity model (Stern et al. 2018). Most of the scholars above just make good use of the national level data without any spatial factors. Comparing to the current studies, we try to set up a theoretical model 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.

In next part, we outline the optimal control theory framework with the general equilibrium structure in the determination of the energy intensity. In Section 3, we derive the spatial autoregressive methods from the theoretical framework. The impacts on energy intensity, energy consumption, and economic output are estimated in section 4. Conclusions and further discussion will be presented in section 5.

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:

$$\mathrm{W} = \sum_{t=0}^{T} U(\mathrm{C}_t)\,(\frac{1}{1+\theta})^t \quad (1)$$

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:

$$U(\mathrm{C}_t) = \frac{{\mathrm{C}_t}^{1-\gamma}}{1-\gamma} \text{ for } \gamma > 0 \textit{ and } \gamma \neq 1 \ (2)$$

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:

$$\mathrm{Y}_t = \mathrm{C}_t + \mathrm{I}_t + G_t \quad (3)$$

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 capacity of capital:

$$\mathrm{I}_t = \mathrm{K}_{t+1} - (1-\delta)\mathrm{K}_t \quad (4)$$

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

$$\mathrm{Y}_t = \mathrm{C}_t + G_t + \mathrm{K}_{t+1} - \mathrm{K}_t + \delta\mathrm{K}_t \quad (5)$$

Writing this identity in discrete-time form we have $\mathrm{I}_t = \mathrm{K}_{t+1} - \mathrm{K}_t = \mathrm{Y}_t - \mathrm{C}_t - G_t - \delta\mathrm{K}_t$, where δ is the depreciation rate.

The constraint for numeraire consumption is:

$\mathrm{C}_t = \mathrm{Y}_t - G_t - (\mathrm{K}_{t+1} - \mathrm{K}_t) - \delta\mathrm{K}_t$.So, the change of capital stock can be derived from the (6) and (7):

$$\mathrm{K}_{t+1} - \mathrm{K}_t = \mathrm{Y}_t - \mathrm{C}_t - G_t - \delta\mathrm{K}_t \quad (8)$$

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

$$Y_t = Q(\mathrm{K}_t,\mathrm{E}_t,\mathrm{L}_t) = \mathrm{K}_t^a\mathrm{E}_t^b\mathrm{L}_t^d\mathrm{e}^{v_t} \quad (9)$$

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 $(\mathrm{F}_t - \pi\mathrm{F}_t)$, where the depreciation rate is π. Therefore, we define value of changes in the capacity of energy infrastructure as

$$\mathrm{F}_{t+1} = \mathrm{G}_t + (\mathrm{F}_t - \pi\mathrm{F}_t) \ (10)$$

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 $\mathrm{E}_t = \mathrm{f}\mathrm{F}_t\varepsilon_t$, 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:

$$\underset{\mathrm{C}_t,\mathrm{G}_t}{Max} \sum_{t=0}^{T} U(\mathrm{C}_t)\,(\frac{1}{1+\theta})^t$$

$$\text{s.t. } \mathrm{K}_{t+1} - \mathrm{K}_t = \mathrm{K}_t^a(\mathrm{f}\varepsilon_t\mathrm{F}_t)^b\mathrm{L}_t^d - \mathrm{C}_t - G_t - \delta\mathrm{K}_t$$

$$\mathrm{F}_{t+1} = \mathrm{G}_t + (\mathrm{F}_t - \pi\mathrm{F}_t)$$

$$\mathrm{K}_0\text{=}\mathrm{K}^* \text{ and } \mathrm{K}_T \text{ is free}$$

$$\mathrm{F}_0\text{=}\mathrm{F}^* \text{ and } \mathrm{F}_T \text{ is free}$$

$$\mathrm{G}_t \geq 0,\ \mathrm{F}_t \geq 0, K_t \geq 0 \text{ and } L_t \geq 0$$

Hence, we form the current Hamiltonian Function:

$$\mathcal{H}_C = \frac{\mathrm{C}_t^{\,1-\gamma}}{1-\gamma} + (\frac{1}{1+\theta})\varphi_{t+1}[\mathrm{K}_t^a(\varepsilon_t\mathrm{f}\mathrm{F}_t)^b\mathrm{L}_t^d - \mathrm{C}_t - G_t - \delta\mathrm{K}_t] + (\frac{1}{1+\theta})\tau_{t+1}(\mathrm{G}_t - \pi\mathrm{F}_t)$$

The first order conditions are as below:

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

$$\frac{\partial\mathcal{H}_C}{\partial F_t}=\left(\frac{1}{1+\theta}\right)\varphi_{t+1}b\mathrm{A}_t\mathrm{K}_t^a(\mathrm{f}\varepsilon_t)^b\mathrm{F}_t^{b-1}\mathrm{L}_t^d-\left(\frac{1}{1+\theta}\right)\tau_{t+1}\pi=-\,[(\frac{1}{1+\theta})\tau_{t+1}-\tau_t] \quad (12)$$

$$\frac{\partial\mathcal{H}_C}{\partial\mathrm{K}_t}=\left(\frac{1}{1+\theta}\right)\varphi_{t+1}[a\mathrm{A}_t\mathrm{K}_t^{a-1}(\mathrm{f}\varepsilon_t\mathrm{F}_t)^b\mathrm{L}_t^d-\delta]=-\,[(\frac{1}{1+\theta})\varphi_{t+1}-\varphi_t] \quad (13)$$

The solutions of the optimal control model above is as follow

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

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

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

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

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

According to $\mathrm{E}_t=\mathrm{f}\varepsilon_t\mathrm{F}_t$, we obtain the optimal energy consumption function

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

If we let $\beta=\frac{bf\varepsilon_t}{\pi+\theta-\delta}$, then the energy consumption function can be expressed as:$E_t=\beta Y_t$. Therefore, there should be a parameter B satisfies that

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

In terms of (9), we can obtain: $lnY_t=aln\mathrm{K}_t+bln\mathrm{E}_t+dln\mathrm{L}_t+v_t \quad (22)$

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

$$lnE_t=B(aln\mathrm{K}_t+bln\mathrm{E}_t+dln\mathrm{L}_t+v_t)+\ln\varepsilon_t$$

$$=Baln\mathrm{K}_t+Bbln\mathrm{E}_t+Bdln\mathrm{L}_t+Bv_t+\ln\varepsilon_t$$

Therefore,

$$lnE_t = \frac{Ba}{1-Ba} ln\mathrm{K}_t + \frac{Bd}{1-Ba} ln\mathrm{L}_t + \frac{Bv_t + \ln \varepsilon_t}{1-Ba} \ (23)$$

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

$$\ln\left(\frac{E_t}{Y_t}\right) = \frac{Ba - a + Baa}{(1-Ba)(1+b)} ln\mathrm{K}_t + \frac{Bd - d + Bad}{(1-Ba)(1+b)} ln\mathrm{L}_t + \frac{Bv_t + \ln \varepsilon_t - v_t + Bav_t}{(1-Ba)(1+b)} \ (24)$$

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

$$lnY_t = \left(a + \frac{bBa}{1-Ba}\right) ln\mathrm{K}_t + \left(\frac{bBd}{1-Ba} + Bd\right) ln\mathrm{L}_t + \left(\frac{Bv_t + \ln \varepsilon_t}{1-Ba} + \ln \varepsilon_t\right) \quad (25)$$

3. Data and Empirical Methods

3.1 Econometric Models

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

$$lnE_{it} = A_0 + \alpha_i + \mu_t + \beta X'_{it} + \frac{Ba}{1-Ba} ln\mathrm{K}_t + \frac{Bd}{1-Ba} ln\mathrm{L}_t + e_{it} \ (26)$$

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 lnY_{it}, which is individual fixed effect. The year effect, μ_t, is also treated as a parameter to be estimated. u_{it} is the error term. And then we also get the extension form from (24):

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

where $A_0 + \alpha_i + \mu_t + \beta X'_{it} + \epsilon_{it} = \frac{Bv_{it} + \ln \varepsilon_{it} - v_{it} + Bav_{it}}{(1-Ba)(1+b)}$. Similarly, we extend (25) into the following form:

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

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

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

$$lnE_{it} = A_0 + \alpha_i + \mu_t + \beta X^{'}_{it} + \frac{Ba}{1-Ba} ln\mathrm{K}_t + \frac{Bd}{1-Ba} ln\mathrm{L}_t + \rho w^{'}_{i} lnE_{it} + \varepsilon_{it} \quad (29)$$

where $\rho w^{'}_{i} lnE_{it} + \varepsilon_{it} = e_{it}$, ε_{it} is the residual for (29) and $\mathrm{w}'_{i}$is the ith row of the spatial weight matrix W. $\rho \neq 0$ 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:

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

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

$$lnY_{it} = A_0 + \alpha_i + \mu_t + \beta X^{'}_{it} + \left(a + \frac{bBa}{1-Ba}\right) ln\mathrm{K}_{it} + \left(\frac{bBd}{1-Ba} + Bd\right) ln\mathrm{L}_{it} + \rho w^{'}_{i} lnY_{it} + \mu_{it} \quad (31)$$

where $\rho w^{'}_{i} lnY_{it} + \mu_{it} = u_{it}$

3.2 Data and Description Statistics

In order to get the estimations from (26) to (31), we collect the panel data (See Figure 1) from 2006 to 2015, which are all from the statistical yearbook of

Guangdong (2007-2016).

Table 2 and 3 present the definitions of variables and summary statistics, respectively. Figure2 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 urbanization is significantly negative associated with energy intensity. Besides, population and investment are also significantly and negatively associated with it, which is against the finding of Li and Lin (2015). The proportion of primary industry and secondary industry are significantly positively associated with it, 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 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 autogressive 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

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 energy intensity has significant spatial spillover effect that 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 energy intensity has significant spatial spillover effect that should be considered in Guangdong, China.

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Author Contributions

Yiming He: Introduction, Theoretical Framework, Data and Econometric Methodology, Conclusion and further discussion;
Heyuan Huang: Empirical Results

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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
Odhiambo (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(201 4)	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	-0.2349	0.3599	-0.8882	0.7118	0.0211	0.0034
ln_gdp	210	7.2328	0.9953	5.4979	9.8036	0.9683	0.0001
ln_ecutgdp	210	6.9979	0.8595	4.9497	9.0948	0.8554	0.0089
utop	210	61.1629	20.2527	34.3500	100	0	0.0023
ln_nep	210	5.4475	0.5650	4.5507	6.8091	0.4531	0.0001
ln_fai	210	6.3144	0.8803	4.6294	8.5952	0.0407	0.1865
fi	210	11.0885	8.1752	0	33.6000	0	0.0412
si	210	48.5676	7.9054	29	65.6000	0	0.9296
sl	210	0.3770	0.1460	0.0667	0.7013	0	0.0914
ml	210	0.3377	0.0974	0.0841	0.5787	0.8869	0.8638
hl	210	0.5883	0.1455	0.2812	0.8543	0	0.2994
_eleven	210	0.5	0.5011	0	1	-	1

Table 4 Hausman test result of Fixed Effect Model

Independent variable	Chi2	Prob>chi2
ln_ecupgdp	15.5700	0.0764
ln_gdp	154.6500	0.0000
ln_ecutgdp	26.8200	0.0015

Table 5 Results of Fixed Effects Models

VARIABLES	ln_ecupgdp	ln_gdp	ln_ecutgdp
utop	-0.0038***	0.0100***	0.0062***
	(0.0010)	(-0.0026)	(-0.0022)
ln_nep	-0.1560***	0.3540***	0.1980**
	(0.0401)	(-0.1030)	(-0.0878)
ln_fai	-0.1370***	0.4260***	0.2890***
	(0.0098)	(0.0251)	(0.0215)
fi	0.0037**	-0.0160***	-0.0123***
	(0.0018)	(0.0048)	(0.0041)
si	0.0060***	-0.0050*	0.0009
	(0.0010)	(0.0027)	(0.0023)
sl	0.0191	-0.2470**	-0.2280***
	(0.0377)	(0.0966)	(0.0825)
ml	0.0225	-0.1460	-0.1230
	(0.0558)	(0.1430)	(0.1220)
hl	-0.0593	0.3990**	0.3400**
	(0.0748)	(0.1920)	(0.1640)
_Ieleven_1	0.0565***	-0.1700***	-0.1140***

	(0.0107)	(0.0273)	(0.0233)
Constant	1.3720***	2.4160***	3.7890***
	(0.2650)	(0.6800)	(0.5810)
Observations	210	210	210
R-squared	0.9170	0.9400	0.9090
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	-0.0021***	0.0062***	0.0047***
	(0.0006)	(0.0016)	(0.0017)
ln_nep	-0.0574**	0.1180*	0.1280*
	(-0.0241)	(-0.0686)	(0.0741)
ln_fai	-0.0332***	0.1720***	0.1730***
	(0.0082)	(0.0228)	(0.0220)
fi	7.41e-05	-0.0061**	-0.0076**
	(0.0011)	(0.0030)	(0.0033)
si	0.0012*	0.0049***	0.0052***
	(0.0006)	(0.0017)	(0.0019)
sl	-0.0387*	-0.1550***	-0.2000***
	(0.0227)	(0.0598)	(0.0658)
ml	0.0109	-0.0445	-0.0463
	(0.0331)	(0.0878)	(0.0971)
hl	0.0368	0.3340***	0.3780***
	(0.0446)	(0.1170)	(0.1290)
_Ieleven_1	0.0218***	-0.6410***	-0.4680***

	(0.0066)	(0.0426)	(0.0549)
Spatial _rho	0.7130***	0.8380***	0.6980***
	(0.0405)	(0.0246)	(0.0392)
Variance_ lgt_theta	-3.8350***	-3.3660***	-3.1360***
	(0.1690)	(0.1920)	(0.1900)
Variance_ sigma2_e	0.0004***	0.0033***	0.0041***
	(4.39e-05)	(0.0003)	(0.0004)
Constant	0.4750***	0.1820	1.3270**
	(0.1780)	(0.4460)	(0.5170)
Observations	210	210	210
R-squared	0.2160	0.4380	0.3720
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

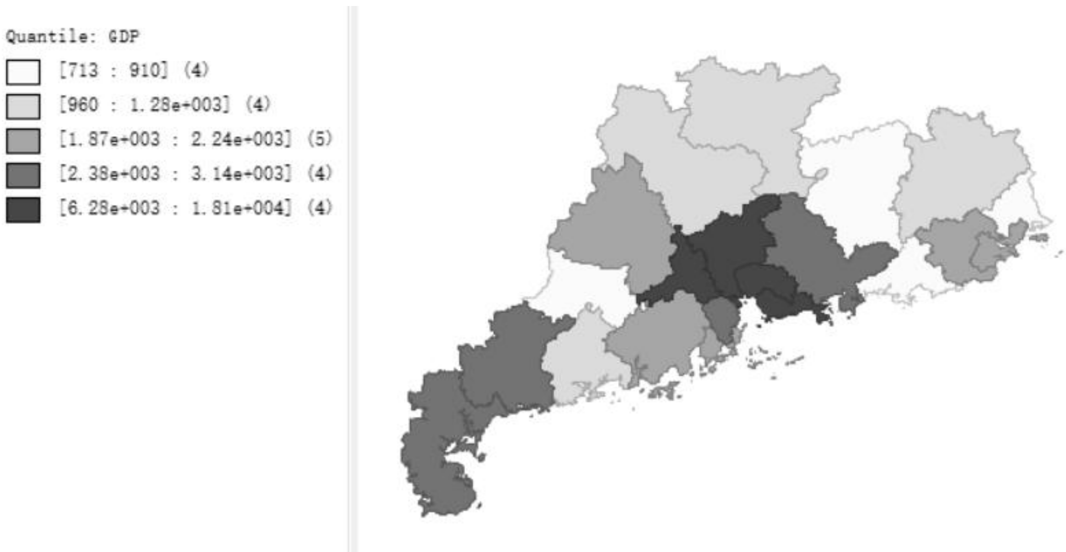

Figure2. 2015 GDP Spatial Distribution Map of Guangdong

Source: Code in Geoda by Authors

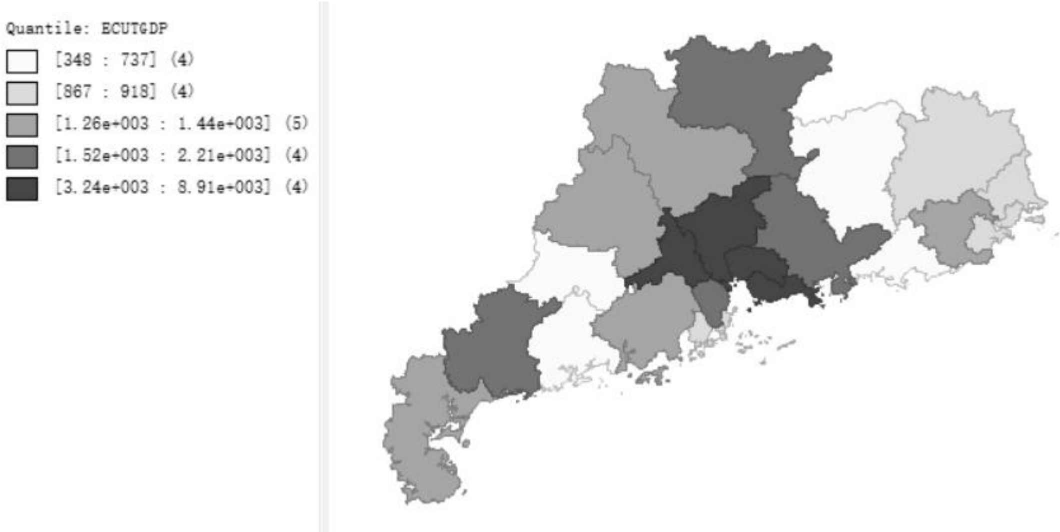

Figure3. 2015 Energy Consumption Spatial Distribution Map of Guangdong

Source: Code in Geoda by Authors

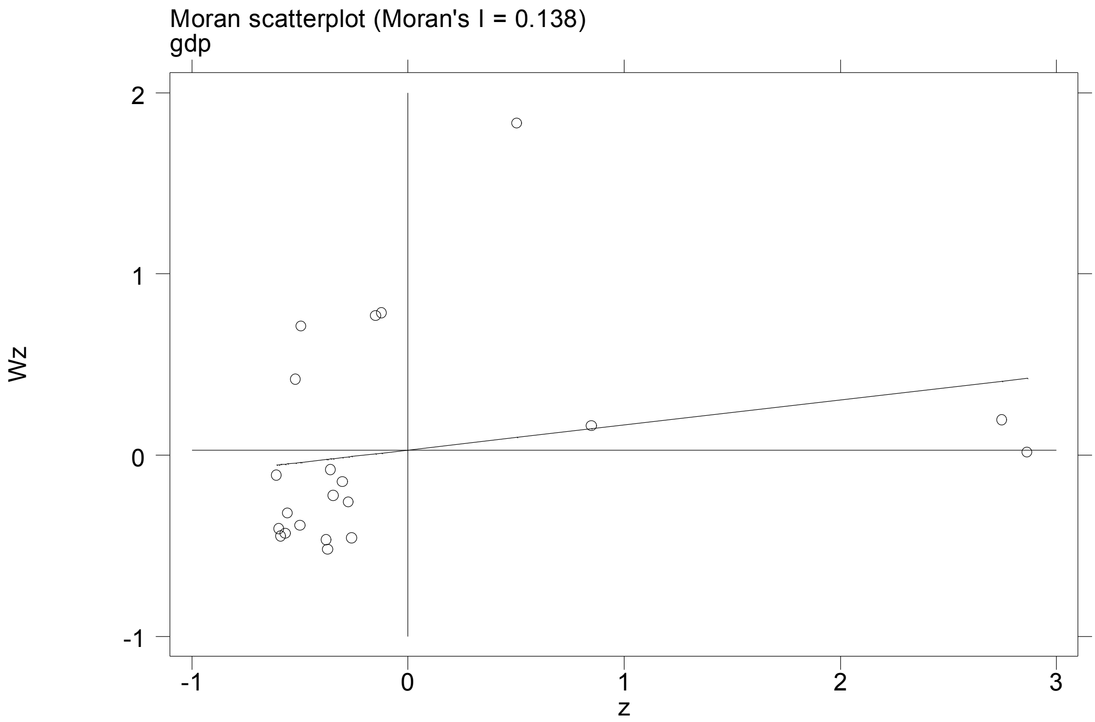

Figure 4. 2015 GDP of Moran Scatter Plot of Guangdong

Source: Code in Geoda by Authors

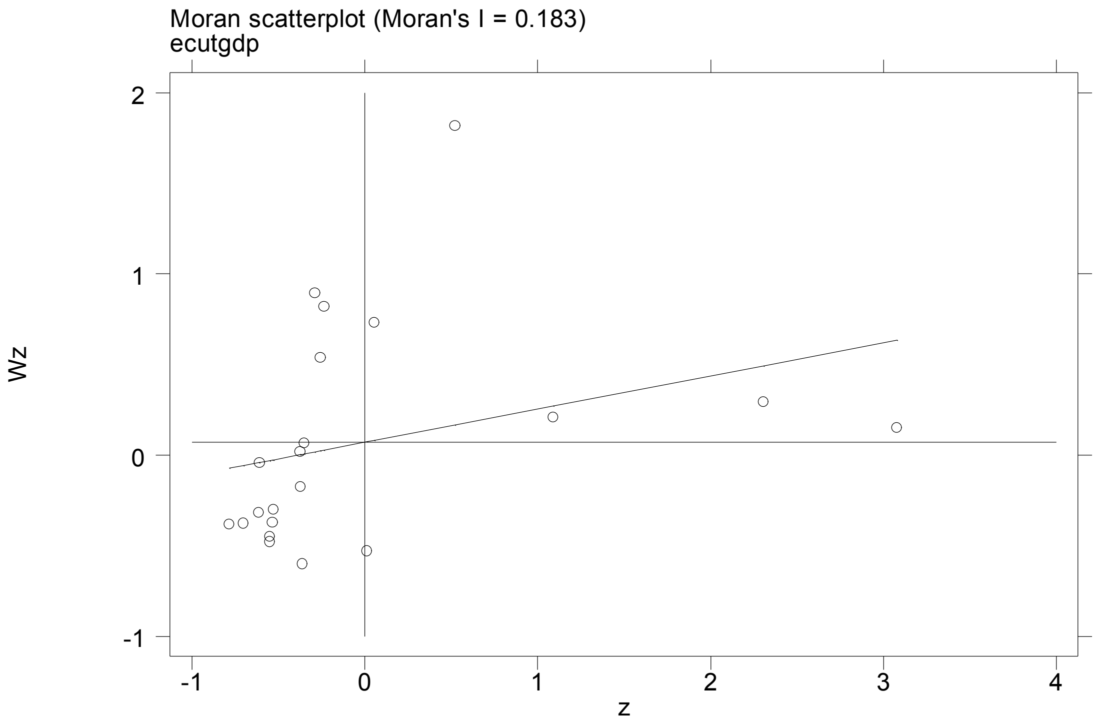

Figure 5. 2015 Energy Consumption of Moran Scatter Plot of Guangdong

Source: Code in Geoda by Authors

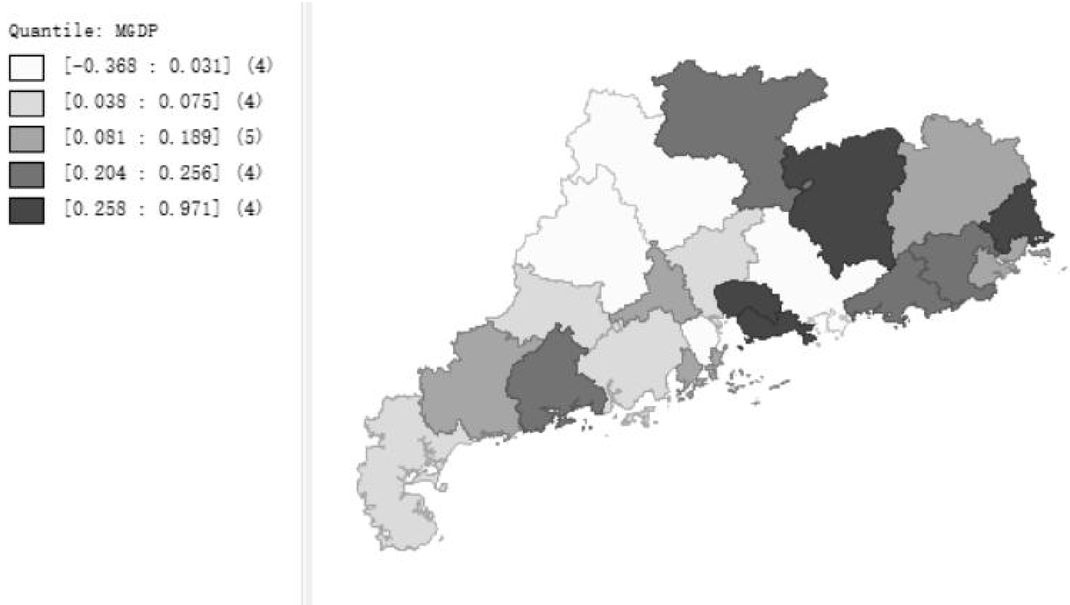

Figure 6. 2015 GDP of Moran Index Map of Guangdong

Source: Code in Geoda by Authors

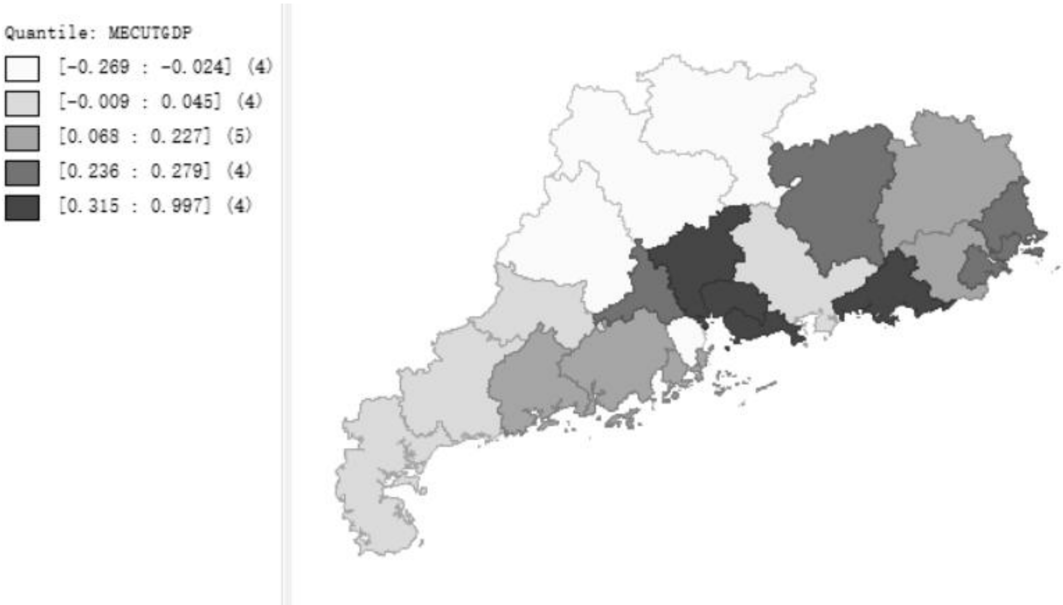

Figure 7. 2015 Energy Consumption of Moran Index Map of Guangdong

Source: Code in Geoda by Authors