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Article

The Relationship between Urbanization, Economic Growth and Energy Consumption in China: An Econometric Perspective Analysis

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Abstract: As the largest developing country in the world, with rapid economic growth, China has witnessed fast-paced urbanization development over the past three decades. In fact, urbanization has been shown to promote economic growth and improve the livelihood of people, but it can also increase energy consumption and further generate energy crisis. Therefore, a better understanding of the relationship between urbanization, economic growth and energy consumption is important for China's future sustainable development. This paper empirically investigates the long-term equilibrium relationships, temporal dynamic relationships and causal relationships between urbanization, economic growth and energy consumption in China. Econometric models are utilized taking the period 1980–2012 into consideration. Cointegration tests indicate that the variables are found to be of $I(1)$ and cointegrated. Further, vector error-correction model (VECM) indicates that when the short-term fluctuations deviate from the long-term equilibrium, the current changes of energy consumption could eliminate 9.74% non-equilibrium error of the last period, putting back the situation to the equilibrium state through a reverse adjustment. Impulse response analysis intuitively portrays the destabilized changes of the variables in response to some external shocks. However, the impact of energy consumption shock on urbanization and the impact of urbanization on economic growth seem to be rather marginal. Moreover, Granger causality results reveal that there is a bi-directional Granger causal relationship between energy consumption and economic growth, and unidirectional causality running from urbanization to energy consumption and economic growth to urbanization. The findings have important implications for Chinese policymakers that on the path towards a sustainable society, the effects of urbanization and economic growth on energy consumption must be taken into consideration.

Keywords: urbanization; economic growth; energy consumption; cointegration test; impulse response analysis; Granger causality test

1. Introduction

Since the implementation of its "Reform and Opening-Up" policy in the late 1970s, China has witnessed, and is still witnessing, fast-paced urban development [1,2]. Over the past three decades, China's urbanization has risen from 17.92% in 1978 to 52.57% in 2012, an average annual growth rate of 1.02% [3]. On the one hand, rapid urbanization has been shown to promote economic development and improve people's living standards [4]; on the other hand, it can also contribute to the increase of energy consumption and consequently generate energy crises [5–8]. As a scarce natural resource, fossil energy has begun to set more limits to urbanization process and economic growth, especially in the context of fossil energy crisis [2]. Furthermore, the tremendous increase of energy consumption may accelerate global warming and climate change, which are considered two of the major issues facing our planet [9–12]. As the largest developing country in the world, with rapid economic growth, China has witnessed fast-paced urbanization development over the past three decades. This rapid growth of the Chinese urbanization and economy has, however, been achieved by huge consumption in energy resources. According to the scientific report, China is now the largest energy consumer. Therefore, the Chinese government's 12th Five-Year Plan (2011–2015) calls for a 16% reduction in energy intensity (energy consumption per unit of GDP) [13]. Under the background of a new round of urbanization and economic development, the issue of energy consumption will become increasingly prominent, and could probably become the bottleneck of urbanization and economic development. Thus, considering the challenges of curbing fossil energy use while maintaining development, it is necessary to investigate the relationship between urbanization, economic growth and energy consumption for developing energy conservation and emission reduction policy [14]. In addition, in order to further determine the direction of the causal relationship between urbanization, economic growth and energy consumption that occurs in China's development process, recent research that contain time series data are necessary.

In recent years, a body of existing literature has estimated the relationship between urbanization, economic growth and energy consumption with various methods. The empirical results, however, are mixed. Many studies discovered that there was a correlated relationship between urbanization, economic growth and energy consumption. For example, studies taken by Jones [15,16] in 59 developing countries found that urbanization was an important factor affecting energy consumption. Similarly, Dahl *et al.* [17] found that urbanization and industrialization had positive effects on energy consumption.

Using a fixed effect analysis, Parikh *et al.* [18] also found that there was a positive relation between urbanization and energy consumption. The results were supported by studies undertaken in relation to the United States by Parshall *et al.* [19]; and in OECD countries by Salim and Shafiei [20]. However, taking Australia, Brazil, Denmark and Japan as study areas, Lenzen *et al.* [21] found that the impact of urbanization on energy consumption varied across countries, even in the same period. In addition, Liddle [22] found that urbanization was important to and correlated with economic growth. However, the impact of urbanization on economic growth varied across regions (countries) based on their level of income and development. Liddle and Messinis [23] further found that urbanization and economic growth either co-evolved in low-income and high-income countries, or else the two processes were decoupled for middle-income and Latin American countries. Ghosh and Kanjilal [24] found that there was a unidirectional causality running from energy consumption to economic activity and economic activity to urbanization in India. Liddle and Lung [25] also found that there was a long-run Granger causality running from electricity consumption to urbanization using various panels. Taking the new EU member as an example, Kasman and Duman [26] found that there was a short-run unidirectional panel causality running from GDP to energy consumption and urbanization to GDP. However, Poumanyvong and Kaneko [27] found that urbanization decreases energy use in the low-income group, while it increases energy use in the middle- and high-income groups. In addition, taking Tunisia as an example, Shahbaz *et al.* [28] demonstrated that there was a long-term causal relationship between urbanization and energy consumption. Similar results were obtained in seven regions by Al-mulali *et al.* [6], in MENA countries by Al-mulali *et al.* [29], in United Arab Emirates by Shahbaz *et al.* [30]. From the above analysis, we learned that most studies focused on the analysis of the relationship between two variables. Little attention has, however, been paid to the estimation of the relationship between three or more variables. Moreover, studies are limited in regarding urbanization as a shift factor when estimating the interactive relationships between variables. This deficiency in contemporary research motivates the present study, which aims to explore the relationship between urbanization, economic growth and energy consumption.

As with the models used in previous studies, cointegration and Granger causality tests have been widely used in exploring the relationship between urbanization, economic growth and energy consumption [31–35]. Little attention has, however, been paid to the utilization of VECM and impulse response analysis. For example, whilst Liu [5,31] found that there was a unidirectional causality running from urbanization to the total energy consumption, they ignored the changes of the variables shocked by external environment (impulse analysis between variables). Similarly, from the perspective of asymmetric adjustment, Liu and Xie [36] provided evidence that there was a non-linear causal relationship between the energy intensity and urbanization. However, due to the lack of impulse analysis, they did not portray the destabilized changes of the variables in response to some external shocks. Similar deficiency also existed in studies taken by Jones [15,16], Liddle [25], Shahbaz and Lean [28], and Du *et al.* [33]. Studies like those listed above essentially measured a limited number of aspects in order to reflect the complex relationship between urbanization, economic growth and energy consumption, neglecting the comprehensive and systematic analysis (VECM and impulse analysis). Although these previous studies have certainly enriched our understanding of the relationship between urbanization, economic growth and energy consumption, they have, as a result, failed to provide adequate and explicit evidence in relation to how urbanization and economic growth in fact affects energy consumption.

In order to deal with this deficiency, this paper first pre-analyzed the locally important time series data from 1980 to 2012 in China, it then subsequently attempts to re-investigate the long-term equilibrium relationships, temporal dynamic relationships and causal relationships between urbanization, economic growth and energy consumption using econometric analysis. First of all, three types of unit root tests are used to examine the stationarity of urbanization, economic growth and energy consumption. If the variables are stationary, cointegration test and vector error-correction model (VECM) are used to examine the long-term equilibrium relationship between urbanization, energy consumption and energy consumption. Based on vector autoregressive (VAR) model, impulse response analysis is utilized to depict the dynamic changes of the variables shocked by external environment. Finally, the causal relationship between urbanization, economic growth and energy consumption will be investigated by Granger causality test.

The rest of this study is organized under three main sections as follows. Section 2 focuses on methods and data, presenting the data pre-processing, the estimation procedure of the econometric models and the data used within the study. Results and discussion are set out in Section 3, and the conclusions and policy implications of the study are summarized in Section 4.

2. Methodology and Data

2.1. Data Source and Pre-Analysis

Annual data for energy consumption were obtained from the China Energy Statistical Yearbooks. Annual data for urban population, the total population and GDP were taken from the online version of the China Statistical Yearbooks. Urbanization level represents the share of urban population to total population. Figure 1 plots the evolution paths of urbanization, economic growth and energy consumption covering the years 1980–2012. From Figure 1, we find that, China's urbanization level was 19.39% in 1980; however, it soared to 52.57% in 2012, with an average increase of 1.02%. As indicated in Figure 1, urbanization level remained stable increase before 1996 (the average annual growth rate is 0.64%), but increased dramatically and continuously after 1996 (the average annual growth rate is 1.38). Over the past three decades, China has generated a spectacular economic development with an annual growth rate at 9.9%. China's gross domestic product (GDP) increased from 454.6 billion Yuan in 1980 to 51,894.2 billion Yuan in 2012, with the result that China is now one of the largest economies in the world. However, rapid urbanization and economic development increased energy consumption in the correspondingly period. Specifically, China's energy consumption hiked from 602.75 million tons in 1980 to 3617.32 million tons in 2012. Before 2000, China's energy consumption kept a steady growth; it then increased dramatically entering the new millennium. Figure 2a–c plot the correlative relationships between urbanization (the independent variable) and energy consumption (the dependent variable), urbanization (the independent variable) and economic growth (the dependent variable), and energy consumption (the independent variable) and economic growth (the dependent variable) respectively. From Figure 2, we find the three variables have strongly correlated links (high R^2). Figure 3 displays a scatter plot and distribution overlay of urbanization, economic growth and energy consumption data in the form of box chart with the bottom and top of the box representing the 25th and 75th centiles. From Figure 3, we find that urbanization rate is highly concentrated at 30%, and mainly dispersed from 25%

to 40%. Energy consumption is mainly distributed between 980 million tons and 2000 million tons, and is concentrated at 1400 million tons (Figure 3). GDP is distributed from 1027.5 to 18,493.7 billion Yuan, with the most concentrated GDP at 8967.7 billion Yuan.

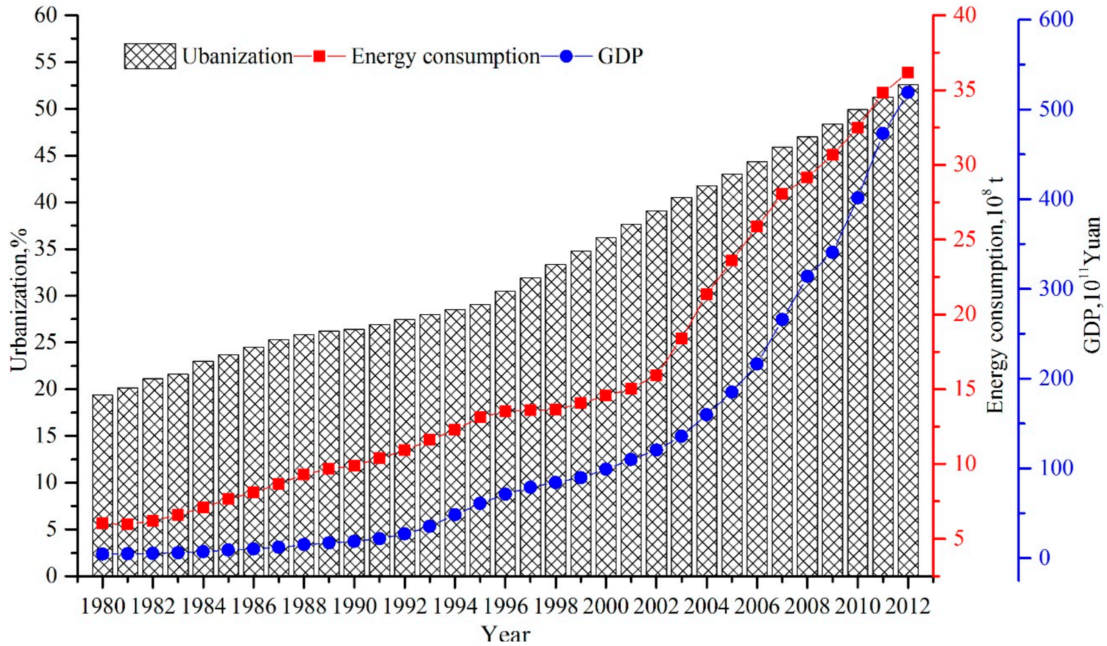

Figure 1. The changing trend of urbanization, economic growth and energy consumption in 1980–2012.

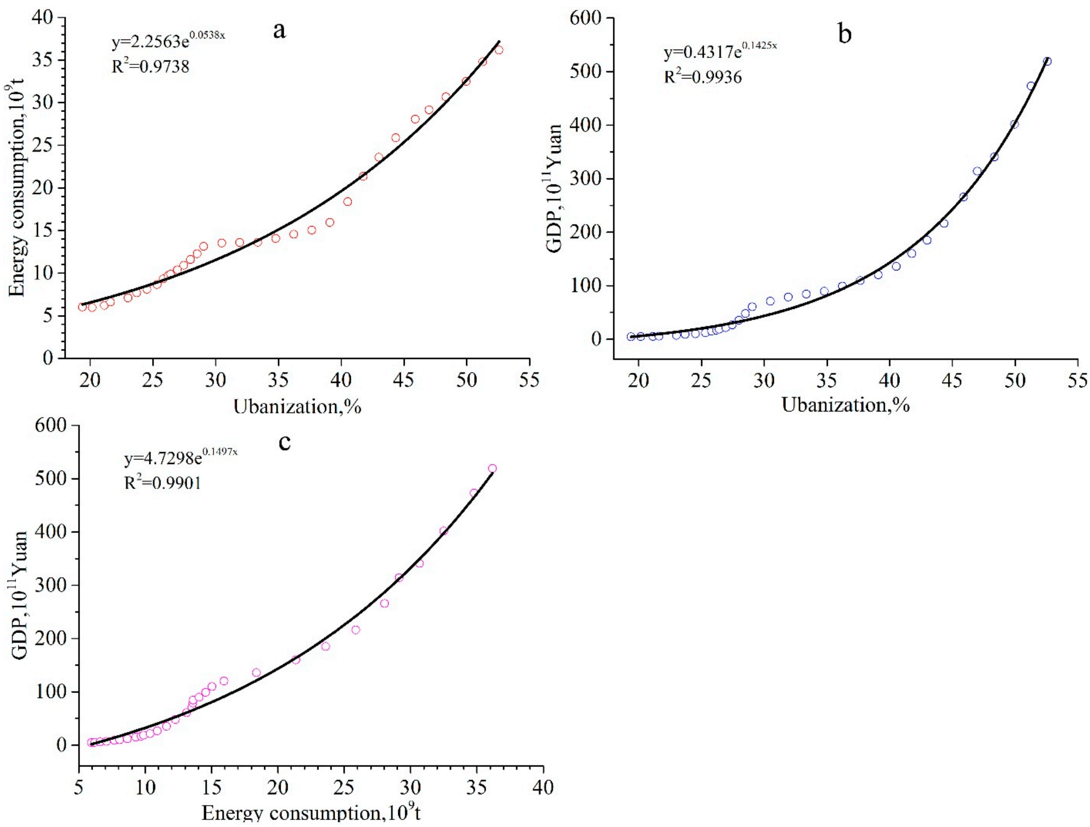

Figure 2. The fitting curve of urbanization, economic growth and energy consumption in China from 1980 to 2012.

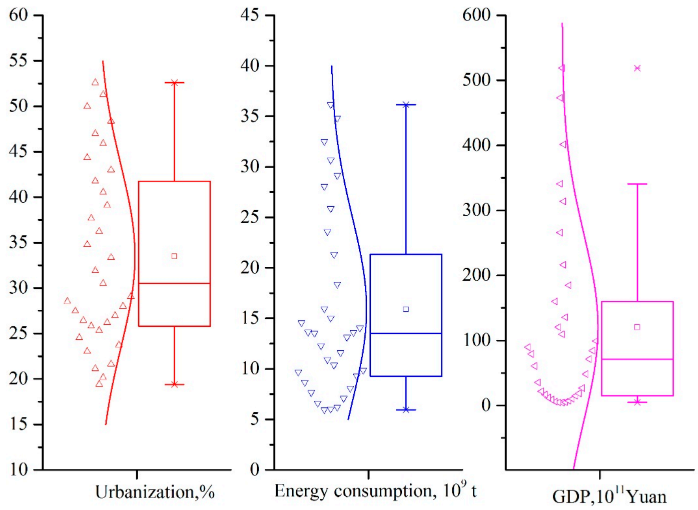

Figure 3. Box chart of urbanization, economic growth and energy consumption with scatter plot and distribution overlay.

2.2. Conceptual Framework

From the pre-analysis, we found that China's urbanization, economic growth and energy consumption share the same convergence trend, indicating that with rapid urbanization and economic growth, energy consumption increased dramatically. In the context of global change, global warming and energy crisis caused by excessive energy consumption now represent a serious threat to human health and the environment. Therefore, it is of great significance to re-investigate the relationship between urbanization, economic growth and energy consumption, and formulate the sustainable development model for promoting the new-type and healthy urbanization theoretically and empirically. To achieve this goal, an estimation procedure will be designed to explore the relationship between urbanization, economic growth and energy consumption (Figure 4).

The unit root tests, namely, ADF, DF-GLS and the PP test will be utilized in this study to examine whether variables are stationary at levels or at the first difference. If the variables are stationary at the first difference, cointegration test and VECM model will be used to the long-term equilibrium relationships. Impulse response analysis based VAR model will be further to portray the dynamic changes of the variables. If the variables are cointegrated, the Granger causality test will be utilized to the casual relationship between the variables.

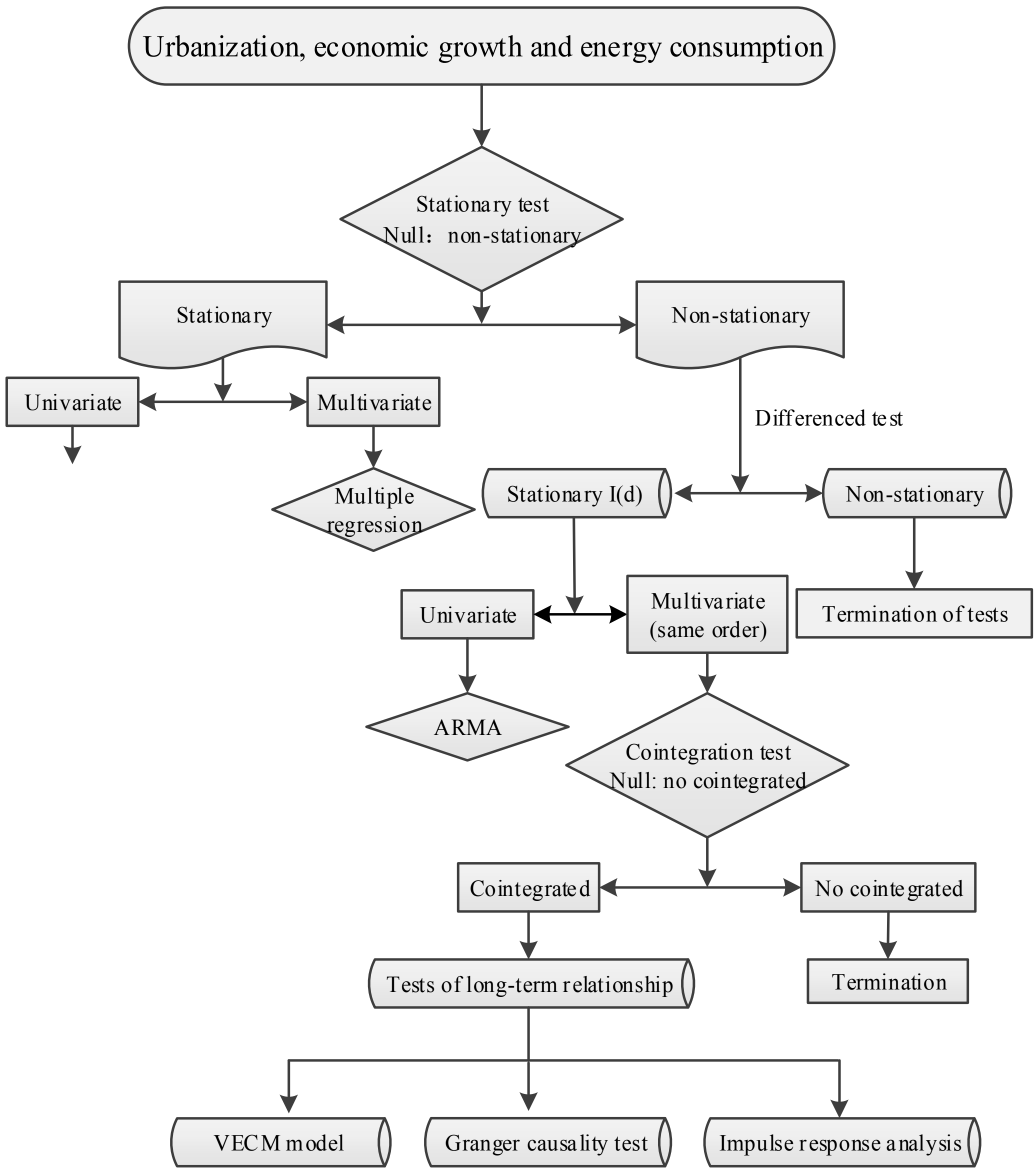

Figure 4. Analysis framework of estimation procedure of urbanization, economic growth and energy consumption.

2.3. Econometric Methodology

Since the main goal of this study is to explore the relationship between urbanization, economic growth and energy consumption, an econometric model will be designed. Before conducting series tests, the natural logarithm of the variables should be used to eliminate the effects of heteroscedasticity in the time series data [2,37]. The econometric model is specified as follows:

$$EC_t = \alpha + \beta URBAN_t + \lambda GDP + \varepsilon_t \quad (1)$$

where *URBAN* represents urbanization level, *EC* denotes energy consumption, GDP represents gross domestic product, *t* represents time, α is the slope coefficient, and ε is the residual errors.

According to Liddle's [22] study, urbanization, which is constrained to be between 0 and 1, cannot technically be integrated of *I*(1). Thus, we transform urbanization (*URBAN*, the share of urban population) to *TURBAN* according to Equation (2). After applying this logistic transformation, the variable is unbounded above and below. We will get the final equation form after inserting Equation (2) into Equation (1). The specific formula of the transformation is as follows:

$$TURBAN = ln(\frac{URBAN}{1-URBAN}) \quad (2)$$

2.3.1. Unit Root Test

Stationary test is an important issue in time series analysis. Stationary test is necessary before conducting regression due to its ability to avoid spurious regression [38]. In general, graphic observation methods and statistical tests are widely used to estimate the stationarity of the variables. However, the latter one always shows higher power [39]. Therefore, we will introduce three types of unit root tests, namely, ADF [40], DF-GLS [41] and the PP [42] test to examine the stationarity of urbanization and energy consumption.

2.3.2. Cointegration Test

If the variables are stationary at the first difference, cointegration analysis, the method proposed by Engle and Granger [43] will be used to examine the long-term relationship between the variables. The essence of cointegration is that the linear combination of variables is stationary [39]. Cointegration tests also require that all variables be integrated of the same order [35]. If series x_t and series y_t have a long-term equilibrium relationship, we can use the following formula to conduct the cointegration test,

$$y_t = \alpha_0 + \alpha_1 x_t + \mu_t \quad (3)$$

where μ_t is residual term, t denotes time.

Dynamic ordinary least square (DOLS) significance test will be used to calculate the non-equilibrium error (e_t),

$$\hat{y}_t = \hat{\alpha}_0 + \hat{\alpha}_1 x_t \quad (4)$$

$$e_t = y_t - \hat{y}_t \quad (5)$$

If e_t is a stable series, we can conclude that series y_t and x_t are cointegrated; otherwise, there does not exist cointegration relationship between series y_t and x_t.

2.3.3. Vector Error Correction Model

Although differenced processing can be used to make the series stationary after the ith difference, they always neglect the important information hidden in the original variables [38]. Therefore, in order to deal with this deficiency, vector error correction model (VECM) is established to eliminate the errors.

Supposing series y and x have the equilibrium relationship. However, many observed variables are always in the neighborhood of the equilibrium point, not exactly at the equilibrium point. Thus, the short-term relationships between variables are commonly estimated. So the distributed lag form should be considered here to investigate the long-term relationship:

$$y_t = \beta_0 + \beta_1 x_t + \beta_2 x_{t-1} + \delta y_{t-1} + \mu_1 \quad (6)$$

From Equation (6), we can find that the change of y_t not only depends on the change of x_t, but also the change of the last period x_{t-1} and y_{t-1}. Considering the non-stationarity, DOLS test cannot be used to perform the regression. Thus, Equation (6) can be deformed to:

$$\begin{aligned}\Delta y_t &= \beta_0 + \beta_1 \Delta x_t + (\beta_1 + \beta_2) x_{t-1} - (1-\delta) y_{t-1} + \mu_t \\ &= \beta_1 \Delta x_t - (1-\delta)(y_{t-1} - \frac{\beta_0}{1-\delta} - \frac{\beta_1 + \beta_2}{1-\delta} x_{t-1}) + \mu_t\end{aligned} \tag{7}$$

or

$$\Delta y_t = \beta_1 \Delta x_t - \lambda (y_{t-1} - \alpha_0 - \alpha_1 x_{t-1}) + \mu_t \tag{8}$$

where $\lambda = 1 - \delta$, $\alpha_0 = \beta_0/(1 - \delta)$, $\alpha_1 = (\beta_1 + \beta_2)/(1 - \delta)$.

2.3.4. Impulse Response Analysis

Vector autoregressive (VAR) model, an improved form of univariate autoregressive (AR) model, extends the AR model to contain more than one variable by regarding exogenous variables as the lagged values of endogenous variables. VAR model are widely used in multivariate time series analysis [38]. VAR (*p*) model is specified as follows:

$$y_t = A_1 y_{t-1} + \cdots + A_p y_{t-p} + B x_t + \varepsilon_t \tag{9}$$

where, y_t is the vector of endogenous variable, x_t is the vector of exogenous variable, p is the lag order, A_1, …, A_p and B is the coefficient matrix, ε_t is the error vector.

Actually, coefficients obtained in classical models can only reflect partly dynamic relationship, not the comprehensive relationship. However, VAR model based on statistics focuses on the whole influencing process of one variable impacting on another. Impulse response analysis can capture and portray the dynamic change. Impulse response analysis based on VAR model is widely utilized to depict the dynamic relationship between variables.

2.3.5. Granger Causality Test

Granger causality tests have been widely utilized to examine the casual relationship between variables. If there is a long-term relationship between two or more variables, Granger causality tests can detect the direction of the casual relationship (unidirectional or bi-directional) [39]. The test model is specified as follows [39]:

$$y_t = \alpha_0 + \sum_{i=1}^{m} \alpha_i y_{t-i} + \sum_{i=1}^{m} \beta_i x_{t-i} + \varepsilon_t \tag{10}$$

$$x_t = \alpha_0 + \sum_{i=1}^{m} \alpha_i y_{t-1} + \sum_{i=1}^{m} \beta_i x_{t-1} + \varepsilon_t \tag{11}$$

The null hypothesis is $\beta_i = 0$, under the null hypothesis *x* does not Granger-cause *y*; if the null hypothesis does is rejected, it can be said that *x* Granger-cause *y*. Similarly, we can examine $\beta_j = 0$ or not to determine whether *y* Granger-cause *x*.

3. Results and Discussion

3.1. Results of Unit Root Tests

Before conducting the cointegration test, the stationarity of the variables should be tested. Under the null hypothesis, H_0, there is a unit root while the alternative hypothesis H_1 there is no unit root. The unit root tests are carried out with individual trends and intercepts for each variable, and the optimal lag lengths are selected automatically using the Schwarz information criteria. The results of the unit root test estimates are reported in Table 1 in both their level and differenced forms. The results in Table 1 clearly show that all variables are not stationary at levels. Therefore, a differenced method is utilized. After conducting the first order difference, we get the differenced forms (ΔTURBAN, ΔEC and ΔGDP). The results of Table 1 further show that all variables are stationary at the first difference rejecting the null hypothesis at less 10% significance. This indicates the variables are found to be of $I(1)$. Thus, this study can proceed with the cointegration test and VECM to examine whether the long run relationship exists between the variables.

3.2. Results of Cointegration Test

Since all the variables are stationary at the first difference, we proceed to perform the cointegration test. First, the residual term e_t should be calculated using DOLS; then, it proceeds to examine the stationarity of e_t using ADF test. From Table 2, we find that e_t is stationary, indicating an cointegrated relationship between urbanization, economic growth and energy consumption. Thus, the estimated regression equation is:

$$\begin{array}{c} EC = 0.5427TURBAN + 0.5041GDP - 2.5434 \\ (8.3123^{***}) \qquad (8.6524^{**})\ (-1.5473^{**}) \end{array} \tag{12}$$

The DLOS test results show that urbanization and economic growth have a long-term relationship with energy consumption. Specifically, 1% increase in urbanization will increase energy consumption by 0.5427% and 1% increase in economic growth will increase energy consumption by 0.5041%. From the results, we can find that both urbanization and economic growth have positive effects on the increase of energy consumption. Along with the rapid urbanization process and economic growth, energy consumption increases accordingly. Therefore, it is not the most feasible method to seek rapid economic growth at the cost of sacrificing the environment in future. Economic growth should be derived from optimizing industrial structure and improving energy efficiency that consume less energy. In dealing with urbanization progress, the Chinese government still faces the dual challenge of reducing environmental pressure (especially reducing energy consumption) while continuing to foster economic development.

Table 1. Unit root test results.

	TURBAN		ΔTURBAN		EC		ΔEC		GDP		ΔGDP	
	Intercept	Intercept and trend	Intercept	Intercept and trend	Intercept	Intercept and trend	Intercept	Intercept and trend	Intercept	Intercept and trend	Intercept	Intercept and trend
DF-GLS	0.256	−1.048	−2.522 **	−3.786 ***	−0.472	−2.418	−2.095 **	−3.073 *	0.282	−2.717	−2.034 **	−3.634 **
ADF	2.761	2.919	−2.656 *	−3.860 **	0.627	−2.235	−2.930 **	−3.046 *	3.167	3.124	−2.731 *	−3.431 *
PP	8.000	1.657	−3.163 **	−3.706 **	0.922	−1.558	−3.319 ***	−3.148 **	13.123	5.368	−0.673	−3.665 *

Note: Δ denotes the first difference; * Denotes significance at 1% level; ** Denotes significance at 5% level; *** Denotes significance at 10% level.

Table 2. Unit root test of residual series e_t.

Series	ADF Test	Critical Value (1% Significant Level)	Critical Value (5% Significant Level)	Critical Value (10% Significant Level)	Stationary/Non-Stationary
e_t	−3.643245	−3.661661	−2.960411	−2.619160	Stationary **

Note: * Denotes significance at 1% level; ** Denotes significance at 5% level; *** Denotes significance at 10% level.

3.3. Vector Error Correction Analysis

If the variables are found to be cointegrated, the vector error correction model will be further used. The model was chosen because it has several advantages. First, it is capable of eliminating the spurious regression using the differenced method. Second, it is more efficient to capture the implicit information of the original variables. In order to enhance the accuracy of the model, error-correction term (*ECM*) will be regarded as the equilibrium error to make up for deficiencies of long-term static model using the short-term dynamic model. The specific regression model is as follows:

$$\begin{aligned}\Delta EC_t = & -0.175 + 0.467\Delta EC_{t-1} + 0.432\Delta TURBAN_t + 0.5714\Delta GDP_t - 0.0974 ECM_{t-1} \\ & (-1.369^{*})\ (4.754^{*}) \qquad (4.965^{**}) \qquad (7.569^{**}) \qquad (-2.683^{*})\end{aligned} \tag{13}$$

From Equation (13), we can find that energy consumption has short-term fluctuations. Energy consumption will deviate from the equilibrium state when impacted by itself or external changes. However, error-correction term (ECM) can precisely explain the fluctuations and the adjustment. Specifically, ECM_{t-1} denotes that under the impacts of control variables, when short-term fluctuations deviate from the long-term equilibrium, changes of energy consumption in *t* period can eliminate the non-equilibrium error of the $t-1$ period by 9.74% and make a reverse adjustment to bring the non-equilibrium state back to equilibrium state. Meanwhile, the changes of the last energy consumption will also lead to the changes of the current energy consumption, with a long-term elasticity coefficient of 0.467. From above analysis, we find that even though the relationship between urbanization, economic growth and energy consumption will deviate from the equilibrium state temporarily after being affected by uncertainties, an equilibrium relationship will manifest in the long run.

3.4. Impulse Response Analysis

Impulse response analysis is widely used to examine how the variables can be destabilized by shocks that arise with other variables. Specifically, impulse response analysis can depict the trajectory of the impact of one standard deviation shock from random disturbance term to the endogenous variable. To obtain additional insight into how the volatility of urbanization, economic growth and energy consumption extent to other variables, we preform impulse response analysis. Figure 5 presents the results from the impulse response analysis.

As shown in Figure 5, a positive one SD shock to energy consumption leads to a decrease in China's urbanization in the first six lag lengths and a slight increase in the last four lag lengths. This indicates that reduction of energy consumption will limit the development of urbanization. However, the impact of energy consumption shock on urbanization is not significant. As expected, a positive one SD shock to urbanization leads an increase in China's energy consumption after the third lag length. In fact, energy consumption has a rapid increase after that lag length, indicating that urbanization shocks have a lagged positive impact on energy consumption. As indicated in Figure 6, a positive one SD shock to energy consumption leads to an immediate increase in China's GDP. This indicates that the impact of the energy consumption shock on economic growth seems to be rather significant. In other words, economic growth has a large dependence on energy consumption. We also find that the impact of economic growth on energy consumption seems to be large. This indicates that with rapid economic growth, energy consumption will increase accordingly. As depicted in Figure 6, economic growth is correlated with urbanization. With the decrease of GDP, urbanization has a decline trend in the same periods. Urbanization shows a lagged positive response to a positive one SD shock of economic growth. Urbanization has an immediate effect on economic growth. However, the impact of urbanization on economic growth seems to be rather marginal.

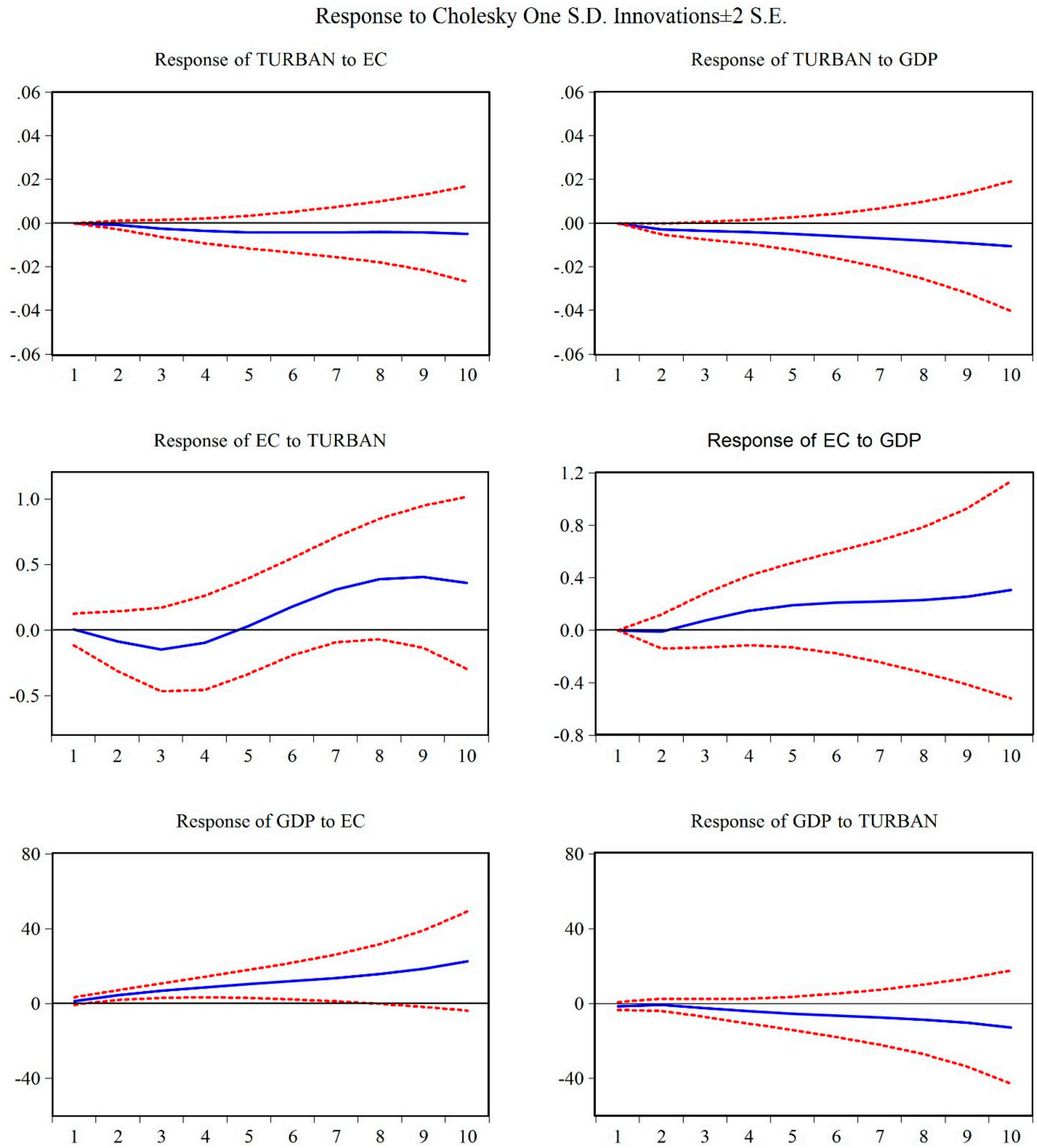

Figure 5. The impulse response curves of urbanization and energy consumption based on VAR model. Note: the solid lines represent impulse response values, the upper and lower dashed lines in each graph denote the 95% confidence interval.

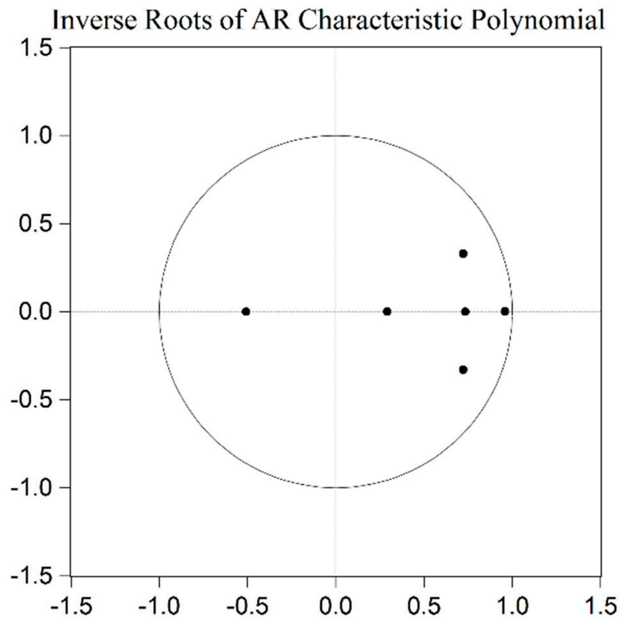

Figure 6. Results of VAR stability condition check.

3.5. Granger Causality Test

Prior to the Granger causality test, the stationarity of the VAR model should be tested. From the Figure 6, we find that all roots are less than 1 and lie inside the unit circle. This indicates that VAR model is stationary. As shown in Table 2, there is a long-term equilibrium relationship between urbanization, economic growth and energy consumption. However, the causal relationships between these variables are unclear. Therefore, the Granger causality test based on VAR model is used. Since the Granger test results are sensitive to the lag length of the variables, an important preliminary step in work the test is to select the lag length of the variables. Four different lag lengths are selected considering the length of the time series. The results of the Granger causality tests are displayed in Table 3.

Table 3. Results of Granger causality tests.

Null Hypothesis		**Lag Lengths**			
		2	**3**	**4**	**5**
TURBAN does not cause EC	F-statistic	9.08466	4.92880	3.83256	1.64663
	Probability	0.0011	0.0091	0.0190	0.02046
EC does not cause TURBAN	F-statistic	0.90827	0.48311	0.69286	2.58952
	Probability	0.4161	0.6974	0.6060	0.1671
GDP does not cause TURBAN	F-statistic	3.68992	3.42977	2.42638	2.21213
	Probability	0.0394	0.0347	0.0836	0.01038
TURBAN does not cause GDP	F-statistic	0.02704	4.77540	4.16935	0.89111
	Probability	0.9734	0.1104	0.1137	0.5099
EC does not cause GDP	F-statistic	3.26069	2.61413	10.4085	3.53027
	Probability	0.0552	0.0767	0.0001	0.0243
GDP does not cause EC	F-statistic	4.23487	1.28459	1.75253	1.58002
	Probability	0.0261	0.03044	0.01802	0.02219

From Table 3, we find that when the null hypothesis is "TURBAN does not cause EC", the minimum *p* of the tests is 0.1671 which is larger than 0.1; thus, we cannot reject the null hypothesis. This indicates that energy consumption does not Granger-cause urbanization. According to the same criterion, we find that there is a bi-directional causal relationship between energy consumption and economic growth, and unidirectional causality running from urbanization to energy consumption and economic growth to urbanization. Therefore, Granger causality tests suggest that a bi-directional Granger causal relationship exists between energy consumption and economic growth, while a one-way Granger causal relationship exists from urbanization to energy consumption and economic growth to urbanization.

4. Conclusions and Policy Implications

In response to global warming, energy saving strategies have been formulated from social and economic perspectives [44]. Increasing attention has been given to the effects on energy consumption caused by urbanization and economic growth. However, quantifying the impacts systematically remains relatively unexplored. As the largest energy consumer, China is facing great pressure to reduce its energy consumption for the mitigation of global warming [45]. According to scientific research, urbanization can promote economic growth and improve the living standards, but it can also increase energy consumption [5–7], and in turn, generate energy crises [7]. Therefore, in order to realize the sustainable development of urbanization, economic growth and energy consumption in China, this paper re-investigates the long-term equilibrium relationships, temporal dynamic relationships and causal relationships between urbanization, economic growth and energy consumption, based on the time series data set covering the period of 1980 to 2012 in China. Unit root tests, E-G cointegration test, vector error-correction model, impulse response analysis and the Granger causality tests base on VAR model are all utilized.

The results of unit root tests indicate that the variables are non-stationary at levels. However, the variables are stationary at the first difference rejecting the null hypothesis. Cointegration test further demonstrates that urbanization and energy consumption are cointegrated. This indicates that there is a long-term equilibrium relationship between urbanization, economic growth and energy consumption: specifically, 1% increase in urbanization will increase energy consumption by 0.5427% and 1% increase in economic growth will increase energy consumption by 0.5041%. As such, urbanization and economic growth have a positive impact on the increase of energy consumption. Further, VECM indicates that when the short-term fluctuations deviate from the long-term equilibrium, the current changes of energy consumption could eliminate 9.74% non-equilibrium error of the last period, putting back the situation to the equilibrium state through a reverse adjustment. Meanwhile, the changes of the last energy consumption will also lead to the changes of the current energy consumption, with an elasticity coefficient of 0.467. Impulse response analysis intuitively portrays the destabilized changes of the variables in response to some external shocks. However, the impact of energy consumption shock on urbanization and the impact of urbanization on economic growth seem to be rather marginal. Moreover, Granger causality results reveal that there is a bi-directional Granger causal relationship between energy consumption and economic growth, and a unidirectional Granger causal relationship from urbanization to energy consumption and economic growth to urbanization.

The above findings thus contribute to the literature and suggest meaningful theoretical and policy implications. Over the past decades, China's economy has increased with an average annual growth rate of 9% [46]. This rapid growth of Chinese economy has however been achieved by huge energy consumption [42]. At present, China is in a period of rapid urbanization, when both industry production and daily life increase the energy consumption. Given the higher growth rate of energy consumption, Chinese policy makers are now paying great attention to the link between urbanization, economic growth and energy consumption. Therefore, the following question is critical for Chinese government: how can China realize the future sustainable development and curb energy use while maintain urbanization development? Due to energy use mainly comes from the process of economic growth and urbanization development, sacrificing economic growth maybe is the most feasible method to address the energy use issue. However, since steady and fast economic growth is always an important goal of Chinese government, direct strategy to curb energy use may lead to many negative impacts, such as unemployment. Therefore, some alternative measures include optimizing industrial structures, energy restructuring, improving energy efficiency and developing low-carbon technology are necessary for Chinese decision makers at central or local levels to address energy security and sustainable economic growth and urbanization development.

From a methodological perspective, this paper underscores the promising aspects of employing econometric models such as unit root models, E-G cointegration tests, vector error-correction model, impulse response analysis, and the Granger causality test in understanding the nexus between urbanization, economic growth and energy consumption. The results of the econometric models are capable of better understanding the causal relationship in China over the period studied. We believe that this analysis process is relevant not only to specific countries such as China and that in fact this analysis method constitutes a critical tool for building a more comprehensive understanding of the complex relationship between urbanization, economic growth and energy use both considering the curbing the energy consumption and maintaining urbanization development in any country or region.

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Author Contributions

Yabo Zhao played an important role in the conception of the study, gathering the data, performing the data analyses, drafting and revising the manuscript. Shaojian Wang contributed to the conceptual framework of this paper, and played an important role in interpreting of the results.

Conflicts of Interest

The authors declare no conflict of interest.

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