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The Causal Relationship between Urbanization, Economic Growth and Water Use Change in Provincial China

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Abstract: The relationship between urbanization, economic growth, and water use change is one of the key issues for China's sustainable development, as rapid urbanization and continuous economic growth are accompanied by a steady water stress. Thus, we applied a cointegration test and a VECM (vector error correction model) Granger causality test to investigate the causal relationship between the urbanization level, the economic development level, and the total water use in China and its 31 provincial administrative regions during 1997–2013. Results show that the three indicators have a long-run equilibrium relationship in most provincial administrative regions in China. However, the short-run effects and Granger causal relationship are insignificant for China and most provincial administrative regions. Therefore, that an idea such as urbanization as the engine or major driving force of economic growth, and that China's urbanization and economic growth will bring a water crisis and will be strongly constrained by water resources, might be properly weakened. Targeted and relatively separate policies should be emphasized more for the coordinated development of China's urbanization, economy, and water resources.

Keywords: urbanization; economic growth; water resources utilization; cointegration test; VECM Granger causality test

1. Introduction

China has experienced a rapid urbanization and economic growth since the reform and open policy launched in 1978. The urbanization level has risen from 17.92% in 1978 to 53.73% in 2013, and its gross domestic product (GDP) has increased from 365 billion yuan to 56,613 billion yuan by more than 160 times at constant prices [1]. The scale and number of cities and towns have also grown. It has brought great challenges to resources and environment, making China one of the largest economies and consumers of resources in the world [2,3]. China's water scarcity is among the great worries [4–6]. In China, the total water use witnessed a sharp increase from 1030 billion m^3 in 1950 to 6183 billion m^3 in 2013, while the total amount of available water resources remained relatively constant and was unevenly distributed. Thus, water shortage and related environmental issues significantly limited the sustainable development of the economy and society in China [7,8]. The relationship between urbanization, economic growth, and water use change has been a research hot spot [9–12].

The nexus of urbanization and economic growth could be traced to the agglomeration economic theory and the growth pole theory. Urban population growth plays an important role in the regional economic development through industrial agglomeration. The correlation between them has been proved by many scholars. For example, Berry [13] chose 95 countries as samples and used the cross-section data to conduct a principal component analysis, finally verifying the relationship between urbanization and the economic development level. Henderson [14] calculated that the correlation coefficient between the urbanization level and the logarithm of per capita GDP is 0.85. Zhou [15] drew a curve of the logarithm for the urbanization and economic development level. Besides, the econometric method is widely applied to examine effects between urbanization and economic growth. For example, Jiang and Huo [16] discovered a long-term equilibrium relationship between urbanization and economic growth through the cointegration test. Liu [17] found that the cointegration relationship and Granger causal relationship vary in different sampled phases in China. However, others suggested that urbanization is not necessarily the direct factor for economic growth, and the growth of cities or metropolises might suppress the growth of towns and countries [18,19]. David *et al.* [20] found that urbanization has no effect on the rate of economic growth, and promoting economic growth via supporting or inhibiting the urbanization process might fail. Therefore, the relationship between urbanization and economic growth should be studied further.

As for water resource utilization, many scholars agree that urbanization and economic growth cause an increase in the total water use. For example, Fitzhugh and Richter [21] took five large urban areas as cases, and demonstrated that urbanization requires a rapid increase of water demand. Jenerette and Larsen [22] reached a conclusion that there is an increase of water required for urban uses. Song *et al.* [23] drew a power function curve to describe the relationship between economic growth and total water use. Bao and Fang [9] inferred a logarithmic curve between urbanization and total water use. However, total water use appeared to decrease while the urbanization level and per capita GDP increased quickly in some Chinese provinces. Some scholars attributed this to the effects of urbanization. For example, Gao [24] revealed a negative feedback relationship by means of comparing the periods of water exploitation and urbanization. Bao and Chen [11] demonstrated that urbanization is capable of optimizing water resource utilization via structure adjustment and efficiency improvement, and has negative effects on the total water use increase. It is thus evident that the relationship between urbanization, economic growth, and water use change has not been clearly revealed.

Therefore, the aim of this paper is to capture the long-run and short-run relationship between urbanization, economic growth, and water use change in China and its 31 provincial administrative regions during 1997–2013, and confirm the causal relationship by means of the econometric method. It might help to understand their relationship using cause and effect. Besides, the direction of causality between urbanization, economic growth, and water use change is important for the implementation of related policies in China. If, for example, water use change causes economic growth, China would have to invest in water use efficiency improvement in order to break the limit of water resources without negatively impacting economic growth. If, on the other hand, economic growth causes a water use increase, then conservative water policies can be implemented without any adverse effect on economic growth. If there is no causality between these variables, then China would have to implement separate policies to affect the levels of the individual variables. Finally, if there is a bi-directional causality between any of these variables, then they are mutually affected and policies need to take into consideration that any change in one will impact the other.

2. Data and Methodology

2.1. Data and Descriptive Statistics

Based on a sample size of 17 years in China and its 31 provincial administrative regions, we conducted bivariate tests between urbanization, economic growth, and water use change. Specifically, urbanization is indicated by the urbanization level, which is defined as the proportion of the urban population in the total population and denoted as *UL* (urbanization level). Economic growth is indicated by gross domestic product (GDP) at a comparable price, and converted to natural log form as *LNGDP* (logarithm of gross domestic product) in order to avoid the problems of non-linear modeling and heteroscedasticity. Water use change is indicated by total water use, and also converted to natural log form as *LNW* (logarithm of total water use).

The above indicators can be directly or indirectly obtained from the *China Statistic Yearbook* and the *China Water Resources Bulletin*. As the population data from the *China Statistic Yearbook* (including China's population census data of six times) have poor comparability among different regions and times [25], Shen [26] modified the total population and urban population from 1982 to 2000 in China and its 31 provincial administrative regions. Based on Shen's research, Fang *et al.* [27] extended the data series to 2005 and established logistic models to predict the future blueprint. For higher comparability, the population data from 1997–2005 were adopted directly those from which Fang *et al.* [27] modified, and the population data from 2006–2013 were adopted from those which Fang *et al.* [27] predicted. For economic data, according to the growth rates compared to the prior year, we converted the GDP from 1997 to 2013 in China and its 31 provincial administrative regions to the constant price in 1997.

2.2. Econometric Methodology

In the traditional economic model, stationary series mixed with non-stationary series may lead to different results and cause false regression. Therefore, Engel and Granger [28] put forward the concept of cointegration, providing the econometric methodology for modeling the non-stationary series. The econometric model has been widely applied in energy and related environmental research [29–31]. However, it has been less frequently applied in water resources management. The empirical econometric model includes the following steps:

2.2.1. Unit Root Test

As non-stationary series could lead to false regression, we must first identify whether the variables belong to stationary or non-stationary series by the unit root test. This test was initially introduced by Dickey and Fuller [32], and the Augmented Dickey-Fuller (ADF) test is now a standard unit test to check the stationarity of the data series. The equation of the form is as follows:

$$\Delta y_t = \gamma y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + u_t \quad (1)$$

where y_t is the variable (*i.e.*, *UL*, *LNGDP* or *LNW*) in period t; Δy_t is the first difference of the variable; p is the lag length for the differenced variable; u_t is a pure white noise error and $u_t \sim i.i.d.N(0, \delta^2)$. The regression coefficients γ and β_i are estimated by the method of ordinary least squares (OLS).

The null hypothesis forecasts y_t as a random walk. We can contrast t-statistics of the coefficient on the lagged level with the relevant critical values given by Fuller [33]. If the calculated t-ratio of the coefficient γ is less than the critical value from the Fuller table, then y_t is said to be stationary.

2.2.2. Cointegration Test

Cointegration means that the linear combination of multiple non-stationary variables may be stationary. If the variables are cointegrated, there may be some long-term equilibrium among these variables. There are many ways to test cointegration, such as ARDL (autoregressive distributed lag), the bound testing approach, the E-G (Engle-Granger) testing approach, and the JJ (Johansen-Juselius) testing approach. Specifically, the JJ testing approach was based on the VAR model (vector autoregressive model) and put forward by Johansen and Juselius [34]. The regression equation is as follows:

$$\Delta y_t = \prod y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + Bx_t + \varepsilon_t \quad (2)$$

where Δy_t is the first difference operator; y_{t-1} and y_{t-i} are the lagged values of variables; x_t is the vector of exogenous variables; Γ_i, Π and B are the coefficient matrices of endogenous and exogenous variables; ε_t is the residual. The rank of matrix Π determines the number of cointegration equations. Matrix Π can be decomposed into $\alpha\beta'$, and β' could be interpreted as the long-run equilibrium relationship among variables; α reveals the speed of the adjustment of y_t to the long-run equilibrium. Due to sample data restriction, the optimal lags were selected by the AIC (Akaike Information Criterion) [35].

2.2.3. VEC (vector error correction) Model and Granger Causality Test

If the variables are cointegrated, we can apply a vector error correction model (VECM) to imply the short-run relationship and the Granger causal relationship among them [28]. The VECM is as follows:

$$\Delta y_t = \delta_t + \alpha \cdot ecm_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + Bx_t + \varepsilon_t \quad (3)$$

where Δy_t is the first difference operator; δ_t is the time trend; ecm_{t-1} is the lagged error correction term which is generated from the long-run relationship. Coefficient α measures the extent to which each dependent variable has a tendency to return to its long-run equilibrium in each short-run period. If α is large and significant, it implies that the dependent variable is largely influenced by the independent variable in the short-run. If α is small or insignificant, it implies that the dependent variable is largely influenced by other variables. Then, Γ_i is the coefficient of Δy_{t-i}, which could be interpreted as the short-run effects of variables. The causality can be found by the significance of the coefficient of Δy_{t-i}. The joint χ^2 statistic for the coefficient of Δy_{t-i} is used for the Granger causality test. The null hypothesis is that the causal relationship exists. If χ^2 is bigger than the critical value, the null hypothesis will be accepted. Otherwise, the null hypothesis will be rejected [36,37].

3. Empirical Results

3.1. Long-Run Relationship

We use ADF test to examine the stationarity of the three variables (*i.e.*, *UL*, *LNGDP*, *LNW*) for China and its 31 provincial administrative regions. The results show that the *t*-statistics for the second difference forms of the three variables are all greater than the critical values at the 5% level. Therefore, we can use the second differences of the three variables to test cointegration. The cointegration vectors and their significance are listed in Table 1. It shows that, in most cases, the cointegration relationships between the three variables in China and its 31 provincial administrative regions are significant. It means that the urbanization level, the economic development level, and the total water use have a long-run equilibrium relationship as a whole. However, there is no significance for the cointegration relationship between *LNGDP* and *UL*, *LNW* and *LNGDP*, *LNW* and *UL* in five, 12, and 13 out of 31 provincial administrative regions. Besides, some levels of significance for the cointegration relationship reach up to 10%. It indicates that the long-run equilibrium relationship between the urbanization level, the economic development level, and the total water use may be variable.

From the cointegration relationship between the three variables, we can obtain the cointegration equation for China and its 31 provincial administrative regions. Take China for example:

$$\mu_t = LNGDP - 10.04URBAN - 7.79 \quad (4)$$

$$LNGDP = 10.04URBAN + 7.79 + \mu_t \quad (5)$$

The above equation indicates that if China's urbanization level increased 1%, the logarithm of the GDP would increase 10.04%. However, the equation is not significant at the 10% level. It means that the positive interaction between urbanization and economic growth is insignificant at the national level in China. Similar implications can also be found from Table 1 for China and its 31 provincial administrative regions to reveal the long-run equilibrium relationship between the three variables (*i.e.*, *UL*, *LNGDP*, *LNW*).

Table 1. Cointegration relationship between urbanization, economic growth, and water use change in provincial China during 1997–2013.

Variables	***LNGDP***	***LNW***	***LNW***	**Variables**	***LNGDP***	***LNW***	***LNW***
Regions	***UL***	***LNGDP***	***UL***	**Regions**	***UL***	***LNGDP***	***UL***
China	−10.04	−0.07 **	−0.87 ***	Henan	−17.10 ***	−0.02	−2.18 ***
Beijing	−13.04 ***	0.26 ***	4.10 ***	Hubei	−11.41 ***	−0.08	144.68 ***
Tianjin	−122.04 ***	0.02 *	−6.58	Hunan	−9.92	−0.08 **	−0.29
Hebei	−14.22 ***	0.11 **	0.87	Guangdong	−11.95 ***	−0.02	0.03 ***
Shanxi	−15.20 *	0.05 **	−2.11	Guangxi	−18.08 ***	0.02	0.05 **
Inner Mongolia	−25.56 ***	−33.33 ***	0.16	Hainan	−7.14	0.04 ***	0.03
Liaoning	−25.83 ***	−0.02 ***	−0.90 ***	Chongqing	−10.85	−2.32 **	−3.20 ***
Jilin	−25.35 ***	−0.13 ***	−8.47 ***	Sichuan	−13.10 ***	−0.01 **	−1.66
Heilongjiang	−6.85 **	−0.14	−0.30	Guizhou	−46.59 ***	0.04	−8.97
Shanghai	−25.69 **	−0.12 *	−2.86	Yunnan	−18.78 ***	−0.03 ***	0.13 ***
Jiangsu	−11.44 ***	−0.13 ***	−0.94 ***	Tibet	−12.74 **	−0.07 **	0.17 ***
Zhejiang	−13.02 ***	0.04	0.35 ***	Shaanxi	−16.27 **	−0.02 **	−1.41 ***
Anhui	−12.68	0.02 ***	−4.95 **	Gansu	−16.39	0.02 ***	0.34
Fujian	−10.51 ***	−0.08	−1.11	Qinghai	−20.17 **	0.13	0.16
Jiangxi	−33.52 ***	−2.03	−7.01 **	Ningxia	−20.69 ***	10.60	2.09 ***
Shandong	−13.55 ***	0.10 ***	0.56 ***	Xinjiang	−16.99 ***	−0.18	−2.48 ***

Note: ***, **, * indicate level of significance at 1%, 5%, and 10% respectively.

Firstly, the cointegration vectors between the economic development level (*LNGDP*) and the urbanization level (*UL*) are all negative, and most equations are significant at the 10% level. It indicates that *LNGDP* and *UL* have a positive correlation with each other in the long run, except in Anhui, Hunan, Hainan, Chongqing, and Gansu. From the absolute values of the cointegration vectors, it can be seen that Tianjin, Inner Mongolia, Liaoning, Jilin, and Shanghai's positive effects are the largest, which indicates that a slight increase in the urbanization level might cause a substantial increase in the economic development level in these provincial administrative regions. However, Heilongjiang, Fujian, Hubei, Jiangsu, and Guangdong's positive effects are the smallest, which indicates that a rapid increase in the urbanization level could cause a limited increase in the economic development level.

Secondly, the cointegration vectors between the total water use (*LNW*) and the economic development level (*LNGDP*) indicate that they have vague correlations in the long run for China and its 31 provincial administrative regions. On the national level and in 11 provincial administrative regions (*i.e.*, Inner Mongolia, Liaoning, Jilin, Shanghai, Jiangsu, Hunan, Chongqing, Sichuan, Yunnan, Tibet, Shaanxi), they have positive correlations. In eight provincial administrative regions (*i.e.*, Beijing, Tianjin, Hebei, Shanxi, Anhui, Shandong, Hainan, Gansu), they have negative correlations. However, in the other 12 provincial administrative regions, the equations are all insignificant.

Finally, the cointegration relationship between the total water use (*LNW*) and the urbanization level (*UL*) is also irregular in the long run. They have positive correlations on the national level and in nine provincial administrative regions (*i.e.*, Liaoning, Jilin, Jiangsu, Anhui, Jiangxi, Henan, Chongqing, Shaanxi, Xinjiang), and have negative correlations in nine provincial administrative regions (*i.e.*, Beijing, Zhejiang, Shandong, Hubei, Guangdong, Guangxi, Yunnan, Tibet, Ningxia). In the other 13 provincial administrative regions, the equations are all insignificant. Moreover, the cointegration relationship between *LNW* and *UL* is not completely consistent with that between *LNW* and *LNGDP*. It also indicates that the cointegration relationship between *LNGDP* and *UL* for China and its 31 provincial administrative regions may be differentiated.

3.2. Short-Run Dynamics and Granger Causal Relationship

We built a bivariate VECM to examine the short-run dynamics and Granger causal relationship between the three variables (*i.e.*, *UL*, *LNGDP*, *LNW*) for China and its 31 provincial administrative regions. The coefficient α and the joint χ^2 statistic for the coefficient of Δy_{t-i} are listed in Table 2.

Firstly, for the economic development level (*LNGDP*) and the urbanization level (*UL*), the short-run effects and Granger causal relationship are insignificant for China and most of the provincial administrative regions. The absolute values of the coefficients α for *LNGDP* and *UL* are all smaller than one. It indicates that economic growth is slightly influenced by urbanization in the short run. On the other hand, the absolute values of the coefficients α for *UL* and *LNGDP* are even smaller. It indicates that urbanization is even more slightly influenced by economic growth in the short run. From the joint χ^2 statistic, it can be seen that there is no causal relationship between urbanization and economic growth in China and most of the provincial administrative regions. However, a bidirectional and positive Granger causal relationship can be found in Guangdong and Yunnan. A unidirectional and positive Granger causal relationship running from urbanization to economic growth can be found in Hebei, Liaoning, Jiangsu, Shandong, Guizhou, and Xinjiang. A unidirectional and positive Granger causal relationship running from economic growth to urbanization can be found in Zhejiang, Jiangxi, Tibet, and Ningxia.

Secondly, for total water use (*LNW*) and the economic development level (*LNGDP*), the short-run effects and Granger causal relationship also appear to be varied. The absolute values of the coefficients α from *LNGDP* to *LNW* are close to or larger than one in most provincial administrative regions, while that from *LNW* to *LNGDP* are almost all smaller than one. It indicates that water use change is largely influenced by economic growth in the short run, while economic growth is largely influenced by other variables rather than water use change in the short run. Moreover, a bidirectional and positive Granger causal relationship can be found only in Jilin. A unidirectional and positive Granger causal relationship running from economic growth to water use change can be found in Tianjin, Inner Mongolia, Liaoning, Jiangsu, Anhui, Shandong, Guangdong, Yunnan, and Gansu. A unidirectional and positive Granger causal relationship running from water use change to economic growth can be found in China, Beijing, Hebei, and Shaanxi. There is no causal relationship in the other 18 provincial administrative regions.

Finally, for total water use (*LNW*) and the urbanization level (*UL*), the overall characteristic of the short-run effects and Granger causal relationship is similar to that for *LNW* and *LNGDP*. Water use change is largely influenced by urbanization in the short run while urbanization is largely influenced by variables other than water use change in the short run. Moreover, a bidirectional and positive Granger causal relationship can be found in Jilin, Jiangsu, Zhejiang, Guangxi, and Xinjiang. A unidirectional and positive Granger causal relationship running from urbanization to water use change can be found in Liaoning, Anhui, Shandong, Henan, Tibet, and Ningxia. A unidirectional and positive Granger causal relationship running from water use change to urbanization can be found in China, Beijing, Jiangxi, Hubei, Shaanxi, and Gansu. There is no causal relationship in the other 15 provincial administrative regions.

Table 2. The VEC model and the causal relationship between urbanization, economic growth, and water use change in provincial China during 1997–2013.

	LNGDP		*UL*		*LNW*		*LNGDP*		*LNW*		*UL*	
	UL		*LNGDP*		*LNGDP*		*LNW*		*UL*		*LNW*	
	α	χ^2	α	χ^2	α	χ^2	α	χ^2	α	χ^2	α	χ^2
China	−0.17	0.90	0.01	2.31	−0.66	0.57	−0.62	7.97 **	−0.89	1.13	−0.11	429.88 **
Beijing	−0.17	7.56	0.01	2.45	0.32	0.39	−0.95	23.00 **	−0.24	6.91	−0.18	29.94 **
Tianjin	−0.04	0.32	0.00	0.05	−0.91	8.87 **	−0.09	0.34	−0.42	0.01	0.00	2.81
Hebei	0.53	24.06 **	−0.01	0.56	1.82	2.62	−1.57	29.83 **	−0.21	1.55	−0.05	0.19
Shanxi	−1.78	2.11	−0.06	2.64	1.85	3.65	−0.07	0.68	−0.45	0.03	−0.01	0.13
Inner Mongolia	0.67	2.02	0.03	1.90	0.06	21.01 **	−0.05	6.94	−0.91	6.61	−0.06	3.35
Liaoning	−0.01	52.87 **	0.00	2.36	−0.56	6.87 **	−0.07	1.56	0.36	10.16 **	−0.07	4.93
Jilin	−0.24	5.73	0.02	3.28	−2.78	12.06 **	−0.46	11.07 **	−0.76	31.42 **	−0.01	28.92 **
Heilongjiang	−0.02	0.73	0.00	0.50	−0.29	2.12	−0.08	1.31	−0.19	1.42	−0.01	2.67
Shanghai	−0.01	1.05	0.07	2.12	−0.80	0.17	−0.02	0.00	−0.79	1.50	0.06	1.36
Jiangsu	0.24	16.53 **	0.01	3.81	−1.91	10.78 **	−0.07	0.44	−1.13	201.41 **	0.03	199.81 **
Zhejiang	0.05	0.78	0.06	10.07 **	−1.52	1.25	−0.24	0.32	−2.24	29.23 **	0.05	8.73 **
Anhui	−0.17	0.81	0.01	0.03	−0.94	8.83 **	−0.10	7.50	−0.87	6.06 **	−0.01	0.03
Fujian	0.07	1.11	0.21	1.39	−0.76	5.51	−0.21	1.16	−1.29	0.34	−0.02	0.22
Jiangxi	0.00	4.00	0.05	52.68 **	0.02	1.26	0.01	0.62	−0.50	0.46	0.01	19.69 **
Shandong	0.67	49.65 **	0.01	2.38	−2.53	14.02 **	0.03	0.46	−3.76	6.57 **	0.01	0.19
Henan	−0.23	4.89	0.02	3.61	−0.88	2.21	−0.17	1.57	−3.58	40.65 **	−0.01	2.27
Hubei	0.45	3.82	0.05	5.63	−0.80	0.99	−0.17	4.46	0.00	7.57	0.00	58.54 **
Hunan	−0.20	3.96	0.03	2.51	−0.81	2.80	0.57	1.64	−1.17	2.02	−0.26	2.01
Guangdong	0.41	14.58 **	0.07	10.60 **	−1.75	6.24 **	0.01	0.13	−2.41	6.43	0.09	6.70
Guangxi	0.04	1.87	0.01	2.08	−1.40	4.03	−0.28	3.96	−4.15	11.81 **	−0.33	8.20 **
Hainan	0.12	2.76	0.14	0.06	−3.19	5.85	0.93	1.23	−0.88	0.36	0.01	1.51
Chongqing	−0.19	0.03	0.02	0.48	−0.37	7.10	−0.07	5.95	−0.62	0.63	0.06	2.17
Sichuan	−0.64	2.32	0.05	1.87	−0.19	1.06	−0.46	3.27	−0.49	2.00	0.00	0.00
Guizhou	−0.24	65.76 **	0.02	0.64	−0.36	0.70	0.26	0.03	0.41	4.94	0.00	0.31
Yunnan	−0.13	6.48 **	0.02	16.10 **	−1.47	6.20 **	−0.29	1.32	−1.00	0.36	0.06	4.63
Tibet	−0.10	0.64	0.01	6.25 **	−0.77	0.85	0.04	1.36	−0.68	23.57 **	−0.04	4.14
Shaanxi	−0.21	4.19	0.02	2.14	−0.21	5.12	−0.52	9.05 **	−1.72	3.51	0.07	25.64 **
Gansu	2.19	0.88	0.01	0.38	−1.86	9.10 **	1.91	2.19	−0.52	0.30	0.09	4.06 **
Qinghai	0.06	0.68	0.07	2.45	−0.50	2.43	0.01	3.45	−0.43	0.00	0.02	0.26
Ningxia	−0.29	5.20	0.05	8.01 **	0.00	0.73	0.00	5.90	−2.52	40.25 **	−0.02	4.12
Xinjiang	0.05	6.97 **	0.04	1.30	−1.35	0.05	−0.21	0.84	−4.48	58.99 **	0.02	35.36 **

Note: ** indicates the existence of a causal relationship at a 5% level.

4. Conclusions and Policy Implications

This study chooses the urbanization level, economic development level, and total water use as indicators to investigate the causal relationship between urbanization, economic growth, and water use change in China and its 31 provincial administrative regions. In summary, the three indicators have a long-run equilibrium relationship in most provincial administrative regions in China. However, the short-run effects and Granger causal relationship are insignificant in most cases. The main conclusions and policy implications go as follows:

(1) The urbanization level and the economic development level have a positive correlation with each other in the long run, while there is no necessary causal relationship between them in most provincial administrative regions of China. For a few provincial administrative regions which have a bi-directional or unidirectional positive Granger causal relationship, the coefficients of the lagged error correction terms are all small, which means that the urbanization level and the economic development level impact each other slightly. Therefore, an idea such as urbanization as the engine or major driving force of economic growth might be properly weakened. During the process of promoting the *New Urbanization Strategy* launched in 2014, China may need to deal with the coordination of urbanization and economic growth with separate policies, and may need to pay more attention to the comprehensive meaning of urbanization [11], *i.e.*, except for the economic growth, China should seek social progress as well as resource and environmental efficiency improvement during its rapid urbanization [38].

(2) Total water use and the economic development level have vague (positive, negative or insignificant) correlations in the long run for China and its 31 provincial administrative regions, and the number of provincial administrative regions of each type accounts for about one-third. The short-run effects and Granger causal relationship also appear varied, and the number of significant and insignificant provincial administrative regions accounts for about one-half. On the whole, the causal relationship between them is not significant as expected. Therefore, an idea such as China's economic growth causing a rapid water use increase and being strongly constrained by water resources might be properly weakened. China should develop low water consumption industries to adjust the industrial structure and water use structure, and improve water use efficiency through economic scale effect [39,40]. Thus, China may realize zero growth of water demand [41,42], and the economic growth may not intensively rely on water resources any longer.

(3) Total water use and the urbanization level have positive correlations in China in the long run, and have positive and negative correlations in nine provincial administrative regions each. In the other 13 provincial administrative regions, there are no significant correlations. The overall characteristic of the short-run effects and Granger causal relationship is similar to that for total water use and the economic development level. Specifically, urbanization may cause rapid water use growth in urban built-up areas or in urban agglomerations, but it may not necessarily cause water use growth in a relatively large region. Therefore, an idea such as China's urbanization bringing a water crisis and being strongly constrained by water resources might be properly weakened. China should adjust the urbanization mode and build water-saving cities and societies, and construct water transfer and compensation mechanisms between urban and rural areas (or low- and high-density urban areas) [8]. Thus, China may obtain the decoupling relationship between urban development and water scarcity.

It should be pointed out that a limitation of this method is that, although we can detect the direction of causality, we cannot ascertain the fundamental reason behind it [43]. Furthermore, this method allows us to see the importance of interaction effects between urbanization, economic growth, and water use change from a regional perspective, but we cannot find different characteristics at a rural or urban level. Furthermore, we tested the causal relationship for China and its 31 provincial administrative regions separately, and a spatial cross-regressive VAR framework or panel data may be applied in further studies [43].

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