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Electricity Consumption and Economic Growth in the Beijing-Tianjin-Hebei Agglomeration of China

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Abstract: Nowadays, increased attention is being paid to the causal relationship between electricity consumption and economic growth. This paper attempts to examine the causal relationship between electricity consumption and economic growth for China's Beijing-Tianjin-Hebei agglomeration, using annual data covering the period 1982–2008. In this study, unit root tests, the Johansen co-integration test, and the Granger causality test are applied. The empirical results indicate that the two series (electricity consumption and economic growth) of the three locales (Beijing, Tianjin, and Hebei) are non-stationary. But first differences of the two series are stationary. The results of the Johansen co-integration test indicate that electricity consumption and economic growth are co-integrated in Hebei and Tianjin while this is not the case in Beijing. The Granger causality test implies that there is causality running from electricity consumption to economic growth in all of the three locales. Causality running from economic growth to electricity consumption is found in Hebei and Beijing while this is not the case in Tianjin. This means that an increase in electricity consumption directly affects economic growth and that economic growth also stimulates further electricity consumption in Hebei and Beijing. But in Tianjin, an increase in electricity consumption directly affects economic growth while economic growth cannot affect electricity consumption. These findings can provide useful information for local governments of the three locales to formulate sustainable energy and economic policies. The study is of great significance for circular economy and building a resource-conserving society.

Key words: electricity consumption; economic growth; granger causality; error correction modelling

1 Introduction

1.1 Background

Electricity is a foundation of economic growth and forms one of the essential infrastructural inputs in socio-economic development. The world faces enormous demand for electricity, driven by forces including population growth, industrialization, urbanization and increasing standards of living. The dependence on networked information and communication technologies (ICTs) is growing in modern societies with the extensive use of the Internet. Other ICTs, for example, cell phones and computers, are quite common now. Therefore, companies, households and economies as a whole have huge demands for electricity (Gurgul and Lach, 2012). However, electricity supply and economic growth have never been well-matched in China. Historically, electricity shortages have been prevalent in China since the 1960s. Electricity shortage became especially severe in 2002 and worsened further in 2004. In the latter year, 24 provinces experienced electricity shortages; the total shortage nationwide was 31 GW (Yuan *et al*. 2007).

The increasing demand for electricity driven by rapid economic development in China, on the one hand, is contrary to the objectives of sustainable development. On the other hand, it upgrades production systems and consumption patterns. This has an effect on energy issues and generates new

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challenges such the influence of energy consumption on the environment, utilization of alternative energy, sustainability, causality between economic growth and electricity consumption, etc. Thus, energy economics literature is paying increasing attention to the causal relationship between electricity consumption and economic growth.

In November 15, 2008, the Chinese government adopted an active fiscal policy and a loose monetary policy by introducing an RMB 4 trillion ($580 billion) stimulus package to mitigate the impact of the global financial crisis. Infrastructure construction spending, accounting for approximately 72% of the total package, played a particularly prominent role (McKissack and Xu, 2011). Five hundred billion of the stimulus money was invested in the construction of power plants and grids. It is believed that this package played an important role in maintaining stable and relatively fast growth (Zhou *et al*. 2011). However, the impact of this policy intervention has been much debated among policy makers. Critics maintain that China's stimulus package made matters worse by pumping excessive investment into an economy that was overheated and marked by overcapacity and overinvestment (Ding, 2009; Zhang, 2009a; Zhang, 2009b). To address questions concerning the necessity of investment in the construction of power plants and grids, an investigation of the causal relationship between electricity consumption and economic growth is needed.

Unfortunately, the debate on the nature of this causal relationship is far from being settled. Some empirical studies have identified a causal relationship running from electricity consumption to economic growth (Akinlo, 2009; Chandran *et al*. 2010; Chen *et al*. 2007), while a few others have reported the opposite (Ciarreta and Zarraga, 2010; Ghosh, 2002). The results of these studies differ even on the direction of causality and the long-term versus short-term impact on policies. Identification of the direction of the causal relationship has important policy implications (Mozumder and Marathe, 2007). For instance, if electricity consumption causes economic growth, then development policy should promote electricity consumption. On the other hand, if economic growth is not the result of electricity consumption, electricity conservation policies which reduce electricity consumption will have little or no effect on economic growth (Abosedra *et al*. 2009). Therefore, it is of great importance for policy-makers to identify the direction of the causal relationship between electricity consumption and economic growth.

Although many studies have looked into energy-growth linkage/causality for China (NBSC, 2008; Polemis and Dagoumas, 2013; Shahbaz and Lean, 2012; Shengfeng *et al*. 2012; Tang *et al*. 2013), these studies all focus on the national macroscopic level, while studies of more developed regions are rare. Since some regions in China have experienced urbanization at an unprecedented speed, unique in human history and unlikely to appear again (Li *et al*. 2012), it is essential to do more in-depth studies on a regional scale of the relationship between electricity consumption and economic growth, especially studies of developed regions. Therefore, the Beijing-Tianjin-Hebei (Jing-Jin-Ji) agglomeration, one of the most important economic planning zones and "the third pole" of the Chinese economy (the Zhujiang Delta and Yangtze River Delta are first and second, respectively), is taken as a case study for electricity consumption-economic growth nexus analyses. The aim of this paper is to shed light on the direction of causal relationship between electricity consumption (EC) and economic growth (EG). The design and the implementation of future economic policies and energy policies for the Jing-Jin-Ji agglomeration also can be provided in the study.

In addition to the introductory section (Section 1), the remainder of the paper is organized as follows. The description of the data and the econometric methodologies used in the study are presented in Section 2. Section 3 displays the empirical results and discussion. Conclusions and policy implications are presented in Section 4.

1.2 Literature review

The study of causal relationships between various forms of energy and economic growth started with the seminal work of Kraft in 1978 (Kraft and Kraft, 1978), in which causality was found to run from GNP to energy consumption in the United States. Since then, the link between energy and economic growth has received a great deal of attention from researchers (Ahmed and Azam, 2016; Akarca and Long, 1980; Al-Iriani, 2006; Alper and Oguz, 2016; Asafu-Adjaye, 2000; Hatzigeorgiou *et al*. 2011; Lee and Chang, 2007; Mehrara, 2007; Narayan and Smyth, 2008; Pablo-Romero and De Jesús, 2016). Meanwhile, electricity has become the preferred form of energy in expanding areas related to economic activities. Electricity has been a key factor in improving standards of living and has played a pivotal role in scientific and technological progress. Therefore, this kind of energy is generally thought to be vital for economic growth, and researchers extended their ideas to examine the relationship between electricity consumption and economic growth.

Table 1 summarizes the main findings and methods employed by some earlier studies conducted to explore the causal relationship between electricity consumption and economic growth. The findings of the previous studies on the causal relationship between electricity consumption and economic growth vary across countries and are inconsistent with regards to the direction of the causal relationships (Narayan and Smyth, 2009). Central to the debate is whether electricity consumption promotes, hinders or is neutral to economic growth. In summary, there are four possible hypotheses on the causal relationship between electricity consumption and economic growth: "growth hypothesis", "conservation hypothesis", "neutrality hypothesis" and "feedback

Table 1 Empirical results of causality tests between electricity consumption and economic growth

Authors	country	method	conclusions
Wolde-Rufael (2006)	Kenya	Toda-Yamamoto	No causality
	Sudan	Toda-Yamamoto	No causality
Lee (2006)	UK and Germany	Toda-Yamamoto	No causality
Soytas and Sari (2003)	Indonesia	ECM model	No causality
Murry and Gehuang (1996)	India	Granger-causal test	No causality
	France	Granger-causal test	No causality
	Portugal	Granger-causal test	No causality
	Zambia	Granger-causal test	No causality
Narayan and Prasad (2008)	Austria	Granger-causal test	No causality
	Denmark	Granger-causal test	No causality
	Ireland	Granger-causal test	No causality
	Norway	Granger-causal test	No causality
Ozturk and Acaravci (2011)	Iran	Bound test	No causality
Gurgul and Lach (2011)	Polish	Granger test	No causality
Masih and Masih (1996)	Singapore	VAR model	No causality
Chen *et al*. (2007)	China	ECM model	No causality
	Taiwan	ECM model	No causality
	Thailand	ECM model	No causality
Squalli (2007)	Saudi Arabia	ARDL bound test	EG→EC
Yoo and Kim (2006)	Indonesia	VAR model	EG→EC
Zamani (2007)	Iran	ECM model	EG→EC
Oh and Lee (2004)	Korea	ECM model	EG→EC
Halicioglu (2007)	Turkey	Granger-causal test	EG→EC
Narayan and Prasad (2008)	Finland	Granger-causal test	EG→EC
	Netherlands	Granger-causal test	EG→EC
	Hungary	Granger-causal test	EG→EC
Hu and Lin (2008)	Taiwan	ECM model	EG→EC
Ghosh (2002)	India	ARDL model	EG→EC
Ciarreta and Zarraga (2010)	Spain	Toda-Yamamoto	EG→EC
Kumar Narayan and Singh (2007)	Fiji island	Granger-causal test	EG←EC
Chen *et al*. (2007)	Indonesia	ECM model	EG←EC
	Hong Kong	ECM model	EG←EC
Squalli (2007)	Venezuela	Toda-Yamamoto	EG←EC
Chandran *et al*. (2010)	Malaysia	ECM model	EG←EC
Narayan and Prasad (2008)	Slovak	Granger-causal test	EG←EC
Yoo and Kwak (2010)	Brazil	ECM model	EG←EC
	Chile	ECM model	EG←EC
	Colombia	ECM model	EG←EC
	Ecuador	ECM model	EG←EC
Akinlo (2009)	Nigeria	ECM model	EG←EC
Murry and Gehuang (1996)	Malaysia	Granger-causal test	EG←EC
	Singapore	Granger-causal test	EG←EC
	Turkey	Granger-causal test	EG←EC
	Philippines	Granger-causal test	EG←EC
Aqeel and Butt (2001)	Pakistan	VAR model	EG←EC

(Continued)

Authors	country	method	conclusions
Yu and Hwang (1984)	Philippines	Granger test	EG←EC
Apergis and Payne (2009)	Nicaragua	Panel ECM	EG←EC
Tang (2008)	Malaysia	ARDL model	EG↔EC
Morimoto and Hope (2004)	Sri Lanka	Yang's model	EG↔EC
Paul and Bhattacharya (2004)	India	Granger test	EG↔EC
Ouédraogo (2010)	Burkina Faso	ARDL model	EG↔EC
Muhammad and Lean (2011)	Pakistan	ARDL model	EG↔EC
Yang (2000)	Taiwan	VAR model	EG↔EC
Yoo (2005)	Korea	ECM model	EG↔EC
Jumbe (2004)	Malawi	ECM model	EG↔EC
Yoo (2006)	Malaysia	VAR model	EG↔EC
	Singapore	VAR model	EG↔EC
Ho and Siu (2007)	Hong Kong	ECM model	EG↔EC

Notes: EC and EG denote electricity consumption and economic growth, respectively. "→" and "←" indicate unidirectional causality, while "↔" implies bidirectional causality.

hypothesis". Evidence of any of these hypotheses will have a significant effect on policy.

For many countries, the growth hypothesis, which means that electricity consumption Granger causes economic growth, has been confirmed. Restrictions on electricity are likely to have adverse effects on economic growth, while increases in electricity consumption promote economic growth. Studies that come to this conclusion include Iyke (2015) and Akinlo (2009) for Nigeria, Shengfeng *et al*. (2012) for China, Squalli (2007) for Venezuela, Chandran *et al*. (2010) for Malaysia, Yoo and Kwak (2010) for Brazil, Chile, Colombia and Ecuador, and Kouakou (2011) for Cote d'Ivoire. On the contrary, for other countries, studies such as Narayan and Prasad (2008) for Finland, Netherlands and Hungary, Yoo and Kim (2006) for Indonesia, Halicioglu (2007) for Turkey and Ghosh (2002) for India, revealed the existence of a "conservation hypothesis", that is, economic growth Granger causes electricity consumption, indicating that policies that reduce electricity consumption are likely to have little or no adverse impact on economic growth in these countries. Narayan and Prasad (2008) suggested the existence of a "neutrality hypothesis" in the case of Austria, Denmark, Ireland and Norway, indicating that policies that either increase or reduce electricity consumption do not influence economic growth. Lastly, some studies supported the "feedback hypothesis", such as Polemis and Dagoumas (2013) for Greece, Shahbaz and Lean (2012) for Pakistan, Morimoto and Hope (2004) for Sri Lanka, Jumbe (2004)for Malawi, Tang *et al*. (2013) for Portugal and Ouédraogo (2010) for Burkina Faso. This theory suggests that electricity consumption and economic growth mutually affect each other.

As one might expect, the empirical results mentioned above revealed mixed results in terms of the hypotheses on the causal relationship between electricity consumption and economic growth. To summarize the literature review, an explosion of studies on the relationship between electricity consumption and economic growth have been undertaken, but these have failed to provide clear evidence on the direction of causality between these two variables. The inconsistent results of the studies could be ascribed to the different periods of time studied, alternative econometric methods, different characteristics of countries, and also omitted variables.

2 Methods

2.1 Study area

As economies have grown and electrification has become commonplace, electricity has become an essential input of production, displacing the utilization of other types of energy. It is worth noting that, since 1990, there has been an explosion of the ratio of electricity in total end user energy consumption (Yuan *et al*. 2007). The demand for electricity is stimulated by factors including industrialization, urbanization as well as an upturn in living standards. This paper takes the Beijing-Tianjin-Hebei (Jing-Jin-Ji) agglomeration, an area with rapid economic development in China, as the study area. As shown in Fig. 1, the Jing-Jin-Ji agglomeration, located in the Bohai Bay region, includes one province (Hebei) and two adjacent municipalities (Beijing, Tianjin). These three locales are all provincial administrative regions at the same administrative level. Beijing, which is the capital and the center of politics, economics and culture in China, along with Tianjin, are two of the four municipalities directly administrated by the central government of China (the other two are Shanghai and Chongqing). Hebei is an important industrial province in northern China. One of the most economically vibrant regions in China, the Jing-Jin-Ji agglomeration covers over 2% of Chinese territory and generated more than 10% of the total GDP in 2008 (NBSC, 2008).

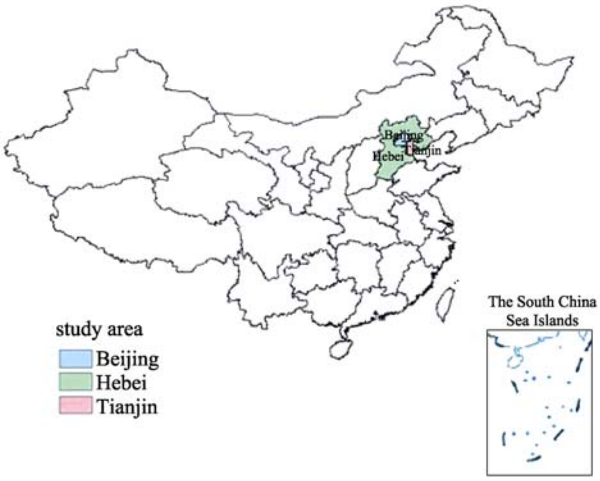

Fig. 1 The study area of Beijing-Tianjin-Hebei (BTH) agglomeration in China

2.2 Variables definition and data sources

Annual data from 1982 to 2008 for Hebei Province, Beijing Municipality and Tianjin Municipality are utilized for this study. The data for the two variables were obtained from *China Statistical Yearbook* (1982-2008). Electricity consumption is expressed in terms of kilowatt hours (kWh) per capita. Real GDP per capita is used as a proxy for economic growth. The nominal GDP series in local currency units are transformed into real GDP series in constant 1978 prices. The use of GDP, rather than gross national product, can be more appropriate in the analysis of the causal relationship, because the system's total electricity consumption depends on goods and services that are produced within the system, not outside the system. The variables used are as follows: lnEC, the natural logarithm of electricity consumption per capita; and lnEG, the natural log logarithm of real GDP per capita.

2.3 Unit root test and co-integration

To conduct Granger causality test, preliminary statistical tests should first be taken to verify the stationarity for all variables. It has been determined that non-stationary data used in causality tests will lead to spurious causality results (Stock and Watson, 1989). Therefore, we employ three usual unit root tests: Augmented Dickey–Fuller test (ADF test) (Dickey and Fuller, 1979), Phillips–Perron test (PP test) (Phillips and Perron, 1988) and Kwiatkowski–Phillips–Schmidt–Shin test (KPSS test) (Kwiatkowski *et al*. 1992) to investigate the order of integration for the selected variables.

If the series are all non-stationary at level but stationary at the same order, the second step is to determine the lag length based on the Akaike information criterion (AIC) and Schwarz information criterion (SIC). Then the co-integration text should be undertaken. The systematic co-movement among two or more variables over the long run is defined as co-integration. According to Engle and Granger (1987), if two variables (X, Y) are both non-stationary, it can be expected that a linear combination of the two variables will generate a random walk. However, if there exists a particular combination of the two variables (X - bY) that is stationary, then the two variables are co-integrated.

In this paper, the Johansen co-integration test (Johansen, 1991) is employed to test for the existence of co-integration.

2.4 Granger Causality

When the existence of co-integration relationships is confirmed, a comprehensive causality test based on an error-correction model (ECM) should be adopted (Engle and Granger, 1987). However, if the variables are non-stationary and no co-integration relationship exists, then the Hsiao version of Granger causality test should be adopted (Toda and Phillips, 1993).

2.4.1 ECM

If two series (X and Y) are non-stationary at level, but first differences of the series lead to stationarity, and the two series are co-integrated, then the ECMs can be expressed as follows:

$$\Delta Y_t = \beta_{10} + \sum_{i=1}^{l_{11}} \beta_{11i} \Delta Y_{t-i} + \sum_{j=1}^{l_{12}} \beta_{12j} \Delta X_{t-j} + \beta_{13} \varepsilon_{t-1} + v_{1t} \quad (1)$$

$$\Delta X_t = \beta_{20} + \sum_{i=1}^{l_{21}} \beta_{21i} \Delta X_{t-i} + \sum_{j=1}^{l_{22}} \beta_{22j} \Delta Y_{t-j} + \beta_{23} \varepsilon_{t-1} + v_{2t} \quad (2)$$

where Y_t and X_t are lnEC and lnEG, respectively. v_t s are error terms, Δ indicates the first differences of the variables. l_{11}, l_{12}, l_{21} and l_{22} represent lag numbers, and $\varepsilon_{t-1}s$ are error- correction terms (ECT).

In both Eq. (1) and Eq. (2), the significance of the short-run causal relationship is tested by the F-statistics of the lagged explanatory variables. On the other hand, long-run causality can be tested according to the significance of the coefficient of ε_{t-1} by t-tests. For example, in Eq. (1), if the coefficients of the lagged *X* are statistically significant, then *X* Granger-causes *Y* in the short-run; and if the estimated coefficient of the lagged value of ε_{t-1} are statistically significant, then *X* Granger-causes *Y* in the long-run.

2.4.2 Hsiao version of Granger causality test

The lag structure of the independent variables has a sensitive effect on the test results for causal relationship. Therefore, to avoid incorrect results of causality caused by absurd lagged variables, choosing an appropriate lag structure is essential In this paper, the model of Hsiao (1981) that combines Akaike (1969) final-prediction-error (FPE) criterion with the standard Granger causality test will be applied.

The models of the standard form of the Granger causality test are as follows:

$$\Delta Y_t = \alpha_{11} + \sum_{i=1}^{l_{11}} \beta_{11i} \Delta Y_{t-i} + u_{11t} \quad (3)$$

$$\Delta Y_t = \alpha_{12} + \sum_{i=1}^{l_{11}} \beta_{11i} \Delta Y_{t-i} + \sum_{j=1}^{l_{12}} \beta_{12j} \Delta X_{t-j} + u_{12t} \tag{4}$$

$$\Delta X_t = \alpha_{21} + \sum_{i=1}^{l_{21}} \beta_{21i} \Delta X_{t-i} + u_{21t} \tag{5}$$

$$\Delta X_t = \alpha_{22} + \sum_{i=1}^{l_{21}} \beta_{21i} \Delta X_{t-i} + \sum_{j=1}^{l_{22}} \beta_{22j} \Delta Y_{t-j} + u_{22t} \tag{6}$$

Akaike's FPE criterion "balances the risk caused by the increase of variance when a higher order is selected and risks caused by bias when a lower order is selected" (Hsiao, 1981). Firstly, the residual sums of squares (RSS) are calculated in Eq. (3) while specifying the lag order (l_{11}) from 1 to l_{11}. Then the lag consideration $\mathrm{FPE}(l_{11})$ can be calculated according to Eq. (7) as follows:

$$\mathrm{FPE}\left(l_{11}\right) = \left[\frac{T + l_{11} + 1}{T - l_{11} - 1}\right] \frac{RSS\left(l_{11}\right)}{T} \tag{7}$$

where T represents the number of samples, and RSS indicates the residuals sum of squares calculated in Eq. (3). For example, if in Eq. (3), l_{11} is set as six, then six $\mathrm{FPE}(l_{11})s$ would be calculated accordingly. The optimal lag length (l^*_{11}) is chosen by the smallest value of $\mathrm{FPE}(l_{11})s$.

Secondly, based on Eq. (4), the modified two-dimensional FPEs are calculated according to Eq. (8) while specifying the lag order (l_{12}) from 1 to l_{12} . The equation of $\mathrm{FPE}(l^*_{11}, l_{12})$ can be expressed as follows:

$$\mathrm{FPE}\left(l^*_{11}, l_{12}\right) = \left[\frac{T + l^*_{11} + l_{12} + 1}{T - l^*_{11} - l_{12} - 1}\right] \frac{RSS\left(l^*_{11}, l_{12}\right)}{T} \tag{8}$$

Then the optimal lag length (l^*_{12}) is chosen when the value of $\mathrm{FPE}(l^*_{11}, l_{12})$ becomes the smallest. Thus the proper lags (l^*_{11}, l^*_{12}) are obtained. According to Hsiao (1981), when $\mathrm{FPE}(l^*_{11}, l^*_{12}) < \mathrm{FPE}(l^*_{11})$, one can say X Granger causes Y. Similarly, based on Eq. (5) and Eq. (6), if $\mathrm{FPE}(l^*_{11}, l^*_{12}) < \mathrm{FPE}(l^*_{21})$ causality from Y to X can be confirmed.

Therefore, Hsiao's version of Granger causality test allows *Y* and *X* to enter into the equation with different lag lengths, resulting in a decrease in the number of lagged variables. Before calculation, the maximum order l_{11}, l_{12}, l_{21}, and l_{22} can be set large enough so that the smallest FPE won't be missed. Factors such as frequency (annual or quarterly) of the time-series and number of variables should be considered when setting the maximum lag length. In this study, we set the maximum lag length to nine, due to the fact that the annual time-series data employed here covers 27 years.

3 Results and discussion

3.1 Stationarity test

The variables are tested for stationarity by ADF tests, PP tests and KPSS tests. Before the testing, all the variables are logarithmic transformed. lnEC is the natural logarithm of electricity consumption per capita and lnEG is the natural logarithm of real GDP per capita.

The results of the ADF, PP and KPSS tests on the integration properties of electricity consumption per capita (lnEC), and real GDP per capita (lnEG) for Hebei Province, Beijing Municipality and Tianjin Municipality are shown in Table 2 and Table 3, both in levels and after one differentiation. The results of the three tests do not establish stationarity for the levels of any of the series, indicating that the lnEC and lnEG series are non-stationary in the three studied districts. Then the variables are differentiated once in order to perform stationarity tests in first differences. The results of the stationarity tests in first differences, based on the ADF tests, PP tests and KPSS tests are presented in Table 3. In Beijing City, although KPSS test rejects the null hypothesis of stationarity at 5% level of significance for *Δ*lnEC, both ADF tests and PP tests suggest stationarity at 1% significant level, indicating that *Δ*lnEC in Beijing City is stationary after one differentiation. According to Table 3, for all the differentiated series, the ADF, PP and KPSS tests suggest stationarity for the three studied districts. According to these results, it was assumed that all the time series of lnEC and lnEG in the studied three districts are integrated of order one.

3.2 Co-integration tests

Having confirmed that all variables included in the causality test are integrated of order one, the next step is to test for the existence of co-integration relationships between EC and EG. For this purpose, the study employs the Johansen's co-integration test. The results of the Johansen's co-integration tests are presented in Table 4. It can be seen that, for Hebei Province

Table 2 Results of ADF, PP and KPSS unit root tests in levels

Variables	ADF test	PP test	KPSS test
Hebei Province			
lnEG	1.027	0.618	0.784***
lnEC	2.17	2.311*	0.771***
Beijing City			
LnEG	0.094	0.246	0.787***
lnEC	0.259	−0.359	0.779***
Tianjin City			
lnEG	1.676	1.514	0.775***
lnEC	2.535	2.536	0.761***
Stationarity	Non-stationary	Non-stationary	Non-stationary

Note: Each ADF, KPSS and PP tests uses an intercept and no trend and lag length has been chosen based on minimum AIC. For ADF and PP tests, *, **, *** represents the rejection of the null hypothesis of non-stationarity at 10%, 5% and 1% level of significance respectively; KPSS denotes Kwiatkowski *et al*. (1992) test, *, **, *** represents the rejection of the null hypothesis of stationarity at 10%, 5% and 1% level of significance respectively. We adopt Bartlett kernel and select the optimal bandwidth using Newey-West bandwidth method.

Table 3 Results of ADF and PP unit root tests in difference levels

Variables	ADF test	PP test	KPSS test
Hebei Province			
⊿lnEG	−5.149***	−3.063**	0.123
⊿lnEC	−2.744*	0.364*	0.062
Beijing City			
⊿lnEG	−4.767***	−4.780**	0.157
⊿lnEC	−5.804***	−5.960***	0.500**
Tianjin City			
⊿lnEG	−3.606**	−2.371**	0.281
⊿lnEC	−2.921*	−2.920**	0.050
ized		0.05	
Stationarity	Stationary	Stationary	Stationary

Note: Each ADF and PP tests uses an intercept and no trend and lag length has been chosen based on minimum AIC. For ADF and PP tests, *, **, *** represents the rejection of the null hypothesis of non-stationarity at 10%, 5% and 1% level of significance respectively. KPSS denotes Kwiatkowski *et al*. (1992) test, *, **, *** represents the rejection of the null hypothesis of stationarity at 10%, 5% and 1% level of significance respectively. We adopt Bartlett kernel and select the optimal bandwidth using Newey- West bandwidth method.

Table 4 Results of Johansen's co-integration tests

Hypothes No. of CE(s)		Trace	0.05	
	Eigenvalue	Statistic	Critical Value	Prob.
Hebei Province None*	0.7839	32.9905	15.4947	0.0001
At most 1	0.0345	0.7370	3.8415	0.3906
Beijing City				
None	0.2188	5.7426	15.4947	0.7257
At most 1	0.0028	0.0636	3.8415	0.8008
Tianjin City				
None*	0.7282	36.3044	15.4947	0.0000
At most 1*	0.3469	8.9463	3.8415	0.0028

Note: * denotes rejection of the null hypothesis at the 0.05 level. The lag structure is determined by the least values of the Akaike information criterion and Schwartz Bayesian Criterion.

and Tianjin Municipality, results reject the null hypothesis that there are no co-integration relationships between EC and EG, indicating that there exists a stable long-run relationship between EC and EG in both Hebei Province and Tianjin Municipality. For Beijing Municipality, we cannot reject the null hypothesis of the absence of co-integration relationships.

For Hebei Province, the null hypothesis of no co-integration relationships between the variables is rejected at the 5% level of significance, but the null hypothesis that at most one co-integrating relationship exists between EC and EG cannot be rejected at the 5% level of significance, indicating that there exists just one co-integration equation at the 5% level of significance. Thus, a long-run relationship between EC and EG is confirmed in Hebei Province.

For Beijing Municipality, the null hypothesis of no co-integration relationship between the variables cannot be rejected at the 5% level of significance, indicating that there does not exist a long-run relationship between EC and EG in Beijing. Due to the non-stationarity of the two variables as well as their linear combination, in the next section, we will employ Hsiao's version of Granger causality test (Toda and Phillips, 1993) for Beijing Municipality.

For Tianjin Municipality, both of the null hypotheses: no co-integration relationship exists and there exists at most one co-integration relationship are rejected at the 5% level of significance. Therefore, the presence of at least two co-integration equations can be confirmed, indicating the existence of a long-run relationship between EC and EG in Tianjin Municipality.

3.3 Hsiao's version of granger causality test

As mentioned above, for Beijing, due to the non-stationarity of the two variables, as well as the linear combination of them, Hsiao's version of the Granger causality test is employed. Table 5 shows the results of Hsiao's version of the Granger causality tests. The F-statistic is calculated under the null hypotheses that there exists no causality relationship between EC and EG in Beijing. According to Hsiao (1981), the result of $\mathrm{FPE}(l^*_{11}, l^*_{12}) < \mathrm{FPE}(l^*_{11})$ indicates that EC Granger-causes EG; similarly, the result of $\mathrm{FPE}(l^*_{21}, l^*_{22}) < \mathrm{FPE}(l^*_{21})$ suggests that EG Granger-causes EC.

For Beijing Municipality, as shown in Table 5, with regard to the EG equation, 0.528<1.052, that is, $\mathrm{FPE}(l^*_{11}, l^*_{12})$ is smaller than $\mathrm{FPE}(l^*_{11})$, indicating that EC Granger-causes EG. We can conclude that a better prediction of the values of EG could be made by including the past values of EC into the EG equation rather than excluding the past values of EG. This is also corroborated by the p-value (0.066), indicating that the null hypothesis of no causal relationship from EC to EG can be rejected at the 10% level of significance.

Table 5 Results of Hsiao's version of the Granger causality test in Beijing City

Beijing City	Regression results			
	l_{11}*/ l_{21}*	l_{12}*/ l_{22}*	FPE(10^{-3})	F- statistic (p-values)
GDP equation				
Eq. (1)	1		1.052	2.987*
Eq. (2)	1	1	0.528	(0.066)
Electricity consumption equation				
Eq. (3)	1		1.439	2.806*
Eq. (4)	1	6	1.074	(0.078)

Note: An FPE represents Akaike (1969) final prediction error. *and ** denote significance of the F-value computed under the null hypothesis of no causality at the 10% and 5% levels, respectively.

According to the results of EC equation derived from Table 5, $\text{FPE}(l^*_{21}, l^*_{22})$ is smaller than $\text{FPE}(l^*_{21})$, thus, EG Granger-causes EC for Beijing. The p-value (0.078) also reveals that the null hypothesis of no casualty from EG to EC can be rejected at the 10% level of significance. We can conclude that a better prediction of EC could be made by including the past values of EG into the EC equation, rather than excluding the past values of EG. In conclusion, there is a bidirectional causality relationship between electricity consumption and economic growth in Beijing Municipality.

Beijing is China's capital city and ranks in the first tier of Chinese cities in terms of economic development and urban construction. For Beijing, increasing economic growth means more free income, resulting in an expansion of consumption in the commercial and domestic sectors where electricity has been a basic and indispensable input. The interdependence between EC and EG may imply that, in Beijing, policies that limit the growth of electricity consumption may have a negative impact on economic growth. Conversely, any potential impact on economic growth can be negatively transmitted back to electricity consumption.

3.4 Granger causality tests based on error–correction model

For Hebei Province and Tianjin Municipality, the existence of a co-integrating relationship between the two variables confirms that there is a long-run equilibrium relationship between the two variables at least in one direction, but the direction of this relationship is not specified (Engle and Granger, 1987). To identify the direction of the causality relationship between the variables and distinguish between "short-run" and "long-run" causality, the Granger causality test based on error correction model (ECM) is employed. The short run causality is connected with policy making in the short run, and the long run causality mainly influences policy making in the long run.

The sources of causality can be identified from the significance test of the coefficients of independent variables in the ECM. With regard to the causality in the short run, we can test the significance of the parameters of dependent variables in each equation of ECM by χ2-Wald statistics. The causality in the long run can be tested by the significance of the coefficients of the ECT, using the t-statistics. The results of Granger causality test based on ECM are shown in Table 6.

It can be seen that for Hebei Province, the causality relationship between EC and EG is bidirectional in the short run. The coefficient of the ECT is found to be significant in Eq. (1) at the 5% level of significance but not in Eq. (2), indicating that there is a unidirectional causality running from EC to EG with no feedback in the long run. In the case of Tianjin Municipality, there exists a unidirectional causality running from EC to EG with no feedback both in the short and long run.

Table 6 Results of Granger causality test based on ECM in Hebei Province and Tianjin Municipality

Dependent variable	Source of causation (short run)		Source of causation (long run)
	⊿(lnEG)	⊿(lnEC)	ECT
Hebei Province			
⊿(lnEG)		14.510**(0.024)	–0.255**(0.022)
⊿(lnEC)	28.487***(0.000)		0.037(0.863)
Tianjin City			
⊿(lnEG)		24.561***(0.000)	2.659**(0.015)
⊿(lnEC)	4.502(0.609)		1.052(0.304)

In Hebei Province, the economy is based on traditional heavy industries that are large consumers of electricity, so the EC Granger causes EG; on the other hand, the Hebei government emphasizes the status of heavy industry and invests a lot in electricity infrastructure and, as a result, the EG also stimulates the EC. As for Tianjin, the economic structure is still secondary industry-dominated, accounting for 60.1%, even though tertiary industry is increasing rapidly. The development of Tianjin's economy is dependent on secondary industry, which is a large consumer of electricity. Besides, Tianjin is a relatively developed district. Except for a part of electricity which is consumed for essential daily activities, the majority of electricity is consumed for economic activities that lead to economic growth. Consequently, EC doubtless Granger causes EG. Hence, the unidirectional causality running from EC to EG emerged, suggesting that restrictions on electricity might limit economic growth, while increasing EC may contribute to EG. So at the end of the research period, the Tianjin government began to invest 28.3 billion in smart electricity infrastructure development during period of "the Twelfth Five-Year Plan" in order to build a harmonious relationship between EC and EG.

3.5 Limitations of the study

This study aimed to examine the causal relationship between electricity consumption and economic growth for the Beijing-Tianjin-Hebei agglomeration in China. The results can provide useful information to help local governments formulate sustainable energy and economic policies. Although the empirical results presented here were specific to the Beijing-Tianjin-Hebei agglomeration, the policy suggestions could be transferable to similar cities in China or elsewhere. However, several issues concerning the research should be noted. Firstly, the time period for a study should be chosen according to the selected model, study objectives and specific situation. In the present study, because an economic stimulus package of 4 trillion Yuan was introduced by the Chinese government in 2008, five hundred billion was invested in construction of power plants and grids. Thus, the time period of 1982–2008 was chosen for our study to identify the causal relationship between electricity consumption and economic growth before the outcome would affected by the stimulus package and then to help verify the necessity of the investment. Secondly, proxies for variables should be selected based on the study objectives. For example, real GDP per capita in this study was used as a proxy for economic growth. Lastly, the choice of models should suit the needs of the study. In the present study, since there were only three locales involved and a comparatively long time series, time series analysis models were chosen. But if there are more cross-section variables and a comparatively short time series, panel data models should be employed.

4. Conclusions and policy implications

This paper is directed towards obtaining a better understanding of causality relationship between electricity consumption and economic growth in the Beijing-Tianjin-Hebei agglomeration during the period of 1982–2008. To achieve this goal, appropriate causality tests based of time-series analyses were employed. In summary, the stationarity of variables was confirmed by ADF, PP and KPSS unit-root tests, and before the application of appropriate Granger causality tests, Johansen co-integration tests were employed to identify co-integration relationships.

Some interesting conclusions emerge from this empirical study. Firstly, the results of the study show that there is a bidirectional causality relationship between EC and EG in Beijing. Secondly, unidirectional causality runs from EC to EG in Tianjin without any feedback effect both in the short and long run. Thirdly, in Hebei, the causality relationship between EG and EC is bidirectional in the short run, while in the long run, Granger causality from EC to EG exists in Hebei, but not vice versa. Overall, the causal relationship between EC and EG is not consistent across the three administrative regions that are the focus of the study.

The observed diversity in the causal relationship patterns is in accordance with expectations. Energy consumption structures and economic policies are known to differ across provincial administrative regions, which makes it natural for provinces and municipalities to have a certain degree of cross-locale variation in the causal relationship patterns between EC and EG. For example, the lack of causality from EG to EC in Tianjin can be accounted for when the fact that the Tianjin government did not focus on the investment in basic electricity infrastructure is taken into consideration. In fact, the proportion of investment in electricity and related industry in Tianjin was only 1.9% in 2008. Therefore, EG is not responsible for a higher level of EC. Economic growth does not lead to more real GDP spending on EC, and thus does not stimulate extra EC.

There are three aspects of the interpretations and implications of the results that merit further discussion. Firstly, it is evident that the existence of causality running from EC to EG is uniform for the three studied districts. That is, a high level of EC leads to a high level of EG in Beijing, Tianjin and Hebei. Obviously, the results significantly reject the neutrality hypothesis that EC is neutral to EG. This implies that electricity shortages will limit economic growth. Although there are many other factors stimulating economic growth, electricity is one of the main factors. However, in the Jing-Jin-Ji agglomeration, even in the whole of China, electricity shortages remain frequent and common (Cheng *et al.* 2013). To avoid the adverse effects of shortages on economic growth, governments and industries should be encouraged to make efforts to raise electricity supply investment. The policy implication is that sustaining economic growth in Jing-Jin-Ji would require continuous development of the region’s electricity sector. To address environmental concerns, however, conventional electricity supply expansion should be accompanied by renewable energy development, increased conservation, and energy efficiency improvements. Meanwhile, with regards to the serious electricity shortages in Jing-Jin-Ji, the Zhujiang Delta and the Yangtze River Delta, the National Energy Board issued an announcement to accelerate the construction of 12 key transmission channels to solve the electricity shortage and air pollution problem.

Secondly, the bidirectional causality relationship between EC and EG also has implications for policy makers in Beijing and Hebei. On the one hand, as presented in the previous paragraph, a causality running from EC to EG generates confidence in decisions to invest in electricity supply infrastructure. On the other hand, the causality running from EG to EC implies that growth in real GDP is responsible for a higher level of electricity consumption. Economic growth results in a growth in the commercial and industrial sectors where electricity is a basic and essential input, and it also leads to higher disposable income which, in turn, raises the demand for household electronic gadgets. Consequently, higher levels of electricity consumption and increasing demand for electricity supply investment are outcomes of economic growth.

Thirdly, since the electricity consumption Granger cause economic growth, and since electricity shortages are frequent and common in the three studied locales, it is essential to invest in existing and new power plants so that the supply of electricity will be adequate to meet increasing demand and to provide the most needed driver of growth in the economy. Thus, the findings in this study confirm the wisdom of China undertaking the 4 trillion yuan ($586-billion) stimulus program in 2008, which adopted strategies and actions to improve China’s integrated electricity planning and invested in construction of power plants and grids.

Finally, there is no universal electricity conservation policy that is adapted to all the needs of locales which are adjacent to each other, since the inter-regional economic context is rather complex and differs in many aspects. Therefore, policy-makers need to take into account various energy consumption structures and economic conditions while formulating electricity consumption and conservation policies.

While these results are suggestive, there are number of areas for future research. Two extensions of the present framework would be fruitful areas for research in the future. Firstly, although most of the existing causality studies of electricity consumption and economic growth employ the Granger causality test that was also adopted in this study, panel causality analyses have the advantage of accounting for both heterogeneity and cross-sectional dependency, which has been shown to induce bias estimates (Pesaran, 2006). Therefore, a study extending to panel Granger causality analysis, for instance, the bootstrap Granger causality procedure based on meta-analysis in heterogeneous mixed panels proposed by Emirmahmutoglu and Kose (2011) would be very interesting. Secondly, the bivariate system employed in this paper can be readily extended to other multivariate systems, where potential omitted variables such as electricity price, employment, capital and labor, are incorporated into the estimation model. Hence, future studies on the causal relationship between electricity consumption and economic growth employing a panel multivariate framework would provide useful information for policy makers to formulate a comprehensive electricity consumption and conservation policies.

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中国京津冀地区电力消费与经济增长

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摘　要：近年来，经济增长与电力消费之间的因果关系受到越来越多的关注。本文利用单位根检验，Johansen 协整检验和 Granger 因果关系检验方法，研究了北京-天津-河北地区 1982-2008 年期间电力消费与经济增长之间的因果关系。实证结果表明，北京、天津和河北三区的电力消费与经济增长的时间序列都是一阶平稳的。Johansen 协整检验的结果表明，在河北和天津，电力消费和经济增长之间存在着协整关系，而在北京，电力消费和经济增长之间则不存在协整关系。我们发现，三个地区均存在着从电力消费到经济增长方向的因果关系，而从经济增长到电力消费方向的因果关系只存在于河北和北京。这意味着，在河北和北京，电力消费的增长将直接影响经济的增长，同时经济增长也将进一步刺激电力消费；但是在天津，电力消费的增加可以直接影响经济的增长，而经济增长则不能影响电力消费。本研究对于发展循环经济和构建资源节约型社会具有重要意义。

关键词：电力消费；经济增长；格兰杰因果关系；误差修正模型