A Nonparametric Analysis of Energy Environmental Kuznets Curve in Chinese Provinces

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2 May 2020

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Abstract: Energy resources are an important material foundation for the survival and development of human society, and the relationship between energy and economy is interactive and complementary. This paper analyzes the energy consumption–economic growth nexus in Chinese provinces using novel and recent nonparametric time-series as well as panel data empirical approaches. The dataset covers 30 provinces over the period of 1980-2018. The empirical analysis indicates the presence of a nonlinear functional form and smooth structural changes in most of the provinces. The nonparametric empirical analysis validates the presence of a nonlinear unit root problem in energy consumption and economic growth, and nonlinear cointegration between the variables. Additionally, the nonparametric panel cointegration test reports evidence of convergence in energy consumption and economic growth patterns across the provinces. The nonparametric regression analysis finds economic growth to have a positive effect, on average, on energy consumption in all provinces, except for Beijing. Further, the energy environmental Kuznets curve exists between economic growth and energy consumption in 20 out of 30 Chinese provinces. The Granger causality analysis reveals the presence of a mixed causal relationship between economic growth and energy consumption. The empirical findings have important implications for Chinese authorities in planning for improving energy efficiency, decoupling between economic growth and energy consumption, and reducing the environmental footprint of provinces.

Keywords: Energy Consumption, Economic Growth, China, Nonparametric Analysis
JEL Classifications: Q43, R11, C14

I. Introduction

China has experienced unprecedented economic growth in the last four decades. China's economic policy to prioritize high economic growth, however, has resulted in China's becoming the largest carbon dioxide (CO_2) emitter in the world. Future projections of China's CO_2 emissions indicate a continuous increase in carbon emissions until 2035/2040 (Andersson and Karpestam 2013, Yuan et al. 2014). The main driver of CO_2 emissions and pollution in China is its increasing demand for energy that is mostly met through the combustion of fossil energy, particularly coal (Bloch et al. 2012, Changhong et al. 2006, Yang et al. 2017). Therefore, any efforts to combat global warming critically depend on China's growth trajectory and a deeper understanding of the decoupling relationship between economic growth and energy consumption. A deeper understanding of energy consumption and economic growth nexus in the context of China will also be crucial for developing effective energy and environmental policies that can put China on the path of sustainable development.

Chinese leadership throughout most of the reform period after 1978 prioritized economic growth at the cost of substantial environmental degradation, resulting in severe air, water, and land pollution (He et al. 2012). Environmentally sustainable development was not emphasized in the first ten five-year plans, and only in the 11th Five Year Plan (2006–2011) that the Chinese government considered focusing on environmentally sustainable development (He et al. 2012, Eaton and Kostka 2017). However, China experienced an uneven pattern of economic growth with coastal provinces leading in terms of economic growth and inland provinces lagging, especially in the early years of the reform period (Andersson et al. 2013). Coupled with this uneven economic growth, China also underwent a gradual capitalist transformation, whereby it became a hybrid economy with a mix of state-owned, private-owned and foreign-own firms instead of only relying on state-owned firms (Nee and Opper 2012). As a result of this uneven capitalist transformation, provinces having a larger share of private-owned firms are likely to more efficient and consume less energy than their counterparts having a smaller share of private-owned enterprises (Andersson et al. 2018).

Additionally, the Chinese government has made targeted efforts to enhance energy efficiency in China (Wang et al. 2018, Hao et al. 2018, Zheng et al. 2018). For instance, the Chinese government actively promoted industrial agglomeration, which had a positive effect on promoting energy efficiency, especially in central and western regions (Liu et al. 2017). The recent upgradation of industrial structure coupled with economic transformation has gradually slowed down the growth in electricity and energy consumption (Ge et al. 2017, Xia and Zhong 2016, Zhang et al. 2019). This indicates that energy consumption might be decoupling from economic growth, and possibly there exists an Energy Environmental Kuznets Curve (EEKC) for some of the Chinese provinces and regions. The theory of EEKC implies that energy consumption is accompanied by economic growth at the early stages of economic development, and after a threshold level of income per capita, energy demand declines due to energy efficiency policies at later stages of economic development. Thus, the relationship between economic growth and energy consumption should be inverted U-shaped. Therefore, our study seeks to exploit the uneven pattern of economic progress across Chinese provinces to establish whether there exists a decoupling relationship between economic growth and energy consumption for Chinese provinces and the existence of EEKC, i.e., inverted U-shaped association.

A growing number of studies have explored the relationship between economic growth, energy consumption, and the environment in the context of China and tested the existence of EEKC (Fei et al. 2011, Li et al. 2011, Xu et al. 2014, Wang et al. 2020, inter alia). These studies, however, provide mixed results in support of the existence of EEKC and the decoupling relationship between economic growth and energy consumption in the context of China and its provinces. One possible explanation for such diverse results is that most of the studies rely on parametric techniques to uncover the relationship between carbon emissions and economic growth. Parametric econometric methods necessitate the imposition of a, often inflexible, linearization of functional form to incorporate the nonlinearity of the EEKC (Li and Racine 2007, Shahbaz et al. 2017a). This involves the incorporation of a squared or other higher-order polynomial versions of the regressor (say per capita GDP) to account for the possible inverted U-shaped relationship between energy consumption and economic growth (see, e.g., Song et al. 2008). As a result, unlike earlier studies such as Li et al. (2011), Zhang and Xu (2012), Zhang et al. (2018), and Dong et al. (2019), this paper undertakes a comprehensive analysis of Chinese provincial data on energy consumption and economic growth by testing for model linearity, stability, non-stationarity, cointegration, and Granger causality. It also conducts regression estimations using only nonparametric techniques.

We use nonparametric techniques because they offer several advantages over their parametric counterparts. Firstly, nonparametric estimators are better able to model cases of complex nonlinearities without making any changes to the functional form, which is often a characteristic of the causal relationship between energy consumption and economic growth (Wagner 2015, Shahbaz et al. 2017a). The nonlinearities in the data generating processes can often lead to over-rejection of the null hypothesis for parametric tests of unit root, cointegration, and direction of Granger causality. This can call into question the reliability and validity of the results, and the inferences made based on them, from parametric studies on the topic (Shahbaz et al. 2017a). Secondly, modeling nonlinearities such as abrupt and/or smooth structural breaks in parametric methods require the parametric specifications to be augmented by dummy variables, which poses a problem for the asymptotic properties of estimation methods when employed to relatively small sample sizes. The nonparametric empirical methods can generate valid estimates in the presence of structural changes, smooth and/or abrupt, that are often characteristic of the energy landscape (Shahbaz et al. 2017a, Shahbaz et al. 2019). Thirdly, nonparametric methods *a-priori* do not require a specification of functional form, which is particularly useful in examining, for example, the EEKC. Examining the EEKC using parametric methods requires the researcher to specify the functional form–whether quadratic, cubic, or polynomial of higher degree–which limits their ability to model phenomenon's complex nonlinearity(ies) (Wagner 2015, Shahbaz et al. 2017a,b). Lastly, nonparametric methods do not necessitate satisfying restrictive regression assumptions such as homoscedasticity, residual normality, and absence of serial correlation, inter alia (Li and Racine, 2007).

This paper contributes to the existing literature in four ways: (i) This paper examines the relationship between energy consumption and economic growth in 30 Chinese provinces by applying an energy demand function in a nonparametric estimation framework. (ii), In contrast to similar past studies, such as Li et al. (2011), Zhang and Xu (2012), Zhang et al. (2018), and Dong et al. (2019), it uses a longer and more recent dataset for the period of 1980-2018 which accounts for the more recent initiatives taken by the Chinese government in improving the country's energy efficiency, emissions targets, and environmental impact of its remarkable growth over the past decades. (iii), This paper tests for and establishes the existence of nonlinearities in energy consumption-economic growth nexus in the Chinese provinces and implements appropriate nonparametric time series and panel tests for nonlinear cointegration, Granger causality, and the long-run correlation between the variables. Past studies such as Li et al. (2011), Zhang and Xu (2012), and Dong et al. (2019) apply parametric panel data estimation techniques to Chinese provincial data to summarize the overall presence of the EEKC for the entire country or select subregions. This study, in contrast, applies nonparametric time series tests to determine the unique nonlinear energy consumption-economic growth nexus in each of the 30 Chinese provinces. In addition, our study is the first to apply a nonparametric panel cross-unit cointegration test to ascertain any nonlinear convergence in either energy consumption, economic growth, or both across the Chinese provinces. (iv), The nonlinear cross-validated local linear (CVLL) nonparametric regression estimator is applied to visually identify the shape of energy consumption-economic growth nexus and identify any instance of the EEKC in each of China's 30 provinces. (v), The nonlinear causality relationship between energy consumption and economic growth is examined by applying Hiemstra-Jones (1994) and Diks-Panchenko (2006) tests.

Our empirical analysis confirms the nonlinear unit root problem in energy consumption and economic growth. The implementation of Pedroni et al. (2015) nonparametric panel cointegration test discovers the first evidence of convergence in energy consumption and economic growth in the majority of Chinese provinces. Economic growth has a positive effect on energy consumption, but in Beijing, economic growth reduces energy consumption. Plotting the CVLL nonparametric regressions, the energy consumption-economic growth nexus displays a range of different and complex nonlinear shapes across the provinces. This study's findings are novel and unique and in stark contrast to prior literature on the Chinese provinces by Li et al. (2011), Zhang and Xu (2012), and Dong et al. (2019) who do not test for the EEKC. In addition, the EEKC can be established in two-thirds of China's province, which is more than the ten detected by Zhang et al. (2018). The empirical analysis is robust as each type of testing–unit root, cointegration, Granger causality, and regression analysis–are performed under two techniques, and the estimated results from both are identical.

The rest of this paper is structured as the following: Section-II briefly reviews the relevant literature, Section-III describes the model and data. Section-IV explains the estimation strategies used in the empirical analysis. Section-V presents the empirical results and relevant discussions, and finally, Section-VI concludes the paper and outlines some policy implications.

II. Literature Review

There exists a dearth of literature on the existence of the Environmental Kuznets Curve (EKC), albeit with mixed results. Several studies provide evidence of the existence of EKC and conclude that there is an inverted U-shaped relationship between CO_2 emissions and economic growth (Coondoo and Dinda 2008, Pao and Tsai 2010, Nasir and Rehman 2011, Riti et al. 2017, Olale et al. 2018). On the contrary, others have failed to find any evidence of the EKC hypothesis (Dijkgraaf and Vollebergh 2005, Ajmi et al. 2013, Kaika and Zervas 2013, Al-Mulali et al. 2015). In addition to this, several other studies conclude that the validity of the inverted-U relationship between CO_2 emissions and economic growth is sensitive to the selection of parameter and data source (Galeotti et al. 2006) as well as the methods used to estimate the relationship (Azomahu and Van Phu 2001, Lin and Jiang 2009, Brajer et al. 2011, Ulucak and Bilgili 2018). Even in the context of China, no consensus on the existence of the EKC emerges. Several studies provide evidence of the existence of EKC hypothesis (Haisheng et al. 2005, Roumasset et al. 2008, Song et al. 2008, Jalil and Mahmud 2009, Yin et al. 2015) while on the contrary others reject the existence of EKC hypothesis in the Chinese context (Du et al. 2012, Yaguchi et al. 2007, Llorca and Meunié 2009, Wang et al. 2011, Govindaraju and Tang 2013, Onafowora and Owoye 2014, Yang et al. 2015). Amongst these, for instance, Yin et al. (2015) and Jalil and Mahmud (2009) provide evidence of the existence of the EKC hypothesis using national-level data. In contrast, Yang et al. (2015), Du et al. (2007), and Yaguchi et al. (2007) fail to establish the existence of the EKC hypothesis.

As highlighted by Luzzati and Orsini (2009, p. 291), however, that the EKC story "is explicitly acknowledged as a black box relationship between income per capita and environmental state/pressures, that is, as a reduced form that arises from a complicated web of determinants and relationships." Given that a significant chunk of anthropogenic CO_2 emissions is driven by energy consumption, more recent studies have started to use energy consumption as an indicator of the environmental pressure and test the existence of the EEKC hypothesis. Kraft and Kraft (1978) were the first ones to explore the energy consumption-economic growth nexus empirically. Their findings suggest that there is a unidirectional causality running from Gross National Product to energy consumption for the post-war period. Subsequently, other studies such as Suri and Chapman (1998), Pablo-Romero and De Jesús (2016), Luzzati and Orsini (2009), Agras and Chapman (1999), Saboori and Sulaiman (2013), Richmond and Kaufmann (2006) amongst others, have empirically explored the energy consumption-economic growth nexus. Ozturk (2010) and Tiba and Omri (2017) provide a comprehensive survey of energy consumption–economic growth and environmental degradation literature.

The studies in the energy consumption-economic growth nexus have employed various econometric techniques for a range of countries and regions in different time periods. Yet so far, no unanimous consensus on the direction of causality. Several studies provide evidence of unidirectional causality running from energy consumption to economic growth for various regions and countries. For instance, Lee (2005) reports long-run and short-run causality from energy consumption to GDP for 18 developing for the period 1975 to 2001. Similar findings were reported by Lee and Chang (2008) for 18 Asian economies for the period 1971-2002. Others have found unidirectional causality running from energy consumption to economic growth for G-7 countries (Narayan and Smyth, 2008) and South America (Apergis and Payne, 2010). On the other end of the spectrum, several studies provide evidence of unidirectional causality running from economic growth to energy consumption (see, e.g., Soytas and Sari 2003, Lee 2006, Lee and Chang 2007, Lise and Van Montfort 2007, Mehrara 2007, Wolde-Rufael 2009, Ozturk et al. 2010). Another strand of literature finds that the causality runs both ways – i.e., there is bidirectional causality between energy consumption and economic growth. Oh and Lee (2004) find the bi-directional causality in the context of Korea, whereas Apergis and Payne (2009) report similar findings in the Commonwealth of Independent States over the period 1991–2005. Others have reported the existence of bi-directional causality between energy consumption and economic growth for developed countries (Lee and Chang, 2007), developing countries (Mahadevan and Asafu-Adjaye, 2007), middle-income countries (Ozturk et al. 2010) and OECD countries (Belke and Potrafke, 2012). Lastly, some studies concluded that there exists no causal relationship between energy consumption and economic growth (Huang et al. 2008, Acaravci and Ozturk 2010, Balcilar et al. 2010, Fallahi 2011).

In the context of China also there is mixed evidence on the existence of EEKC and decoupling relationship between energy consumption and economic growth. Wu, Chen, Zhang, and Cheng (2008) and Fei, Dong, Xue, Liang, and Yang (2011) are one of the earlier studies exploring the relationship between energy consumption and economic growth. Fei et al. (2011) adopt a dynamic panel data approach to investigate the relationship between energy consumption and economic growth for 30 provinces in mainland China from 1985 to 2007. Their results show that there is a positive long-run relationship between real GDP per capita and energy consumption. Moreover, they show that economic growth in east China is more energy-dependent compared to west China. Shahbaz et al. (2013) reported a bidirectional causality between energy demand and economic growth. Zhang and Xu (2012), using Chinese provincial panel data from 1995 to 2008, report that economic growth increases energy consumption in China. This result not only holds at the national level but also at regional and sectoral levels with the Eastern Region and industrial sector, indicating a bidirectional causality between energy consumption and economic growth. Dong et al. (2019), using provincial-level data from 1985–2014 and the panel threshold regression model, find no evidence of a nonlinear relationship for the whole country. However, they find a single threshold for both eastern and non-eastern regions with the elasticity of GDP not varying significantly before and after the threshold. This result lends little support for an EEKC and the decoupling hypothesis.

Rahman et al. (2020) explore the relationship between energy production, energy consumption, and gross domestic product (GDP) growth in China for the period 1981–2016. Their results of Hatemi-J and FMOLS tests supported long term cointegration in the consumption and production of coal, oil, and natural gas. Further, they confirm the presence of the long-term positive impact of the consumption and production of coal, oil, and natural gas on GDP growth. Hao et al. (2016) provide strong evidence for the "inverted-U" shaped relationship between per capita coal consumption and the GDP per capita. On the other hand, Zhang et al. (2018) find the heterogeneous relationship between energy consumption per capita and GDP per capita across provinces. Their results show that for most provinces, there is a linear relationship with no presence of the inflection point of energy consumption per capita. Whereas, for some provinces, they report that the estimated relationship is "inverted-U" or "inverted-N" shaped, suggesting the existence of decoupling of energy consumption per capita and GDP per capita. This result is mostly in line with the investigation of EKC relationship by Liu et al. (2008) and Song et al. (2013) who find that at the provincial level, there exist remarkable differences in the inflection point of EKC hypothesis across regions and provinces, indicating that some regions and provinces in China already passed the inflection point whereas, some regions still require years to reach it.

In view of the inconclusive empirical support for the EEKC hypothesis, specifically in the case of China, there is a need to re-investigate the EEKC relationship between energy consumption and economic growth (Table-A1 in Appendix A summarizes the findings of earlier studies). One of the main drawbacks of earlier studies is that they rely on parametric approaches to uncover the relationship. That means making specific assumptions regarding the shape of the relationship. This study takes a different approach by estimating the EEKC hypothesis using non-parametric techniques that enable us to estimate the relationship without making any prior assumptions. Hence, our approach is likely to provide a more holistic perspective on the existence of EEKC between energy consumption and economic growth in the regions and provinces in China.

III. Model and Data

The empirical analysis involves evaluating the relationship between energy consumption (EC) and economic growth (Y), using data for 30 Chinese provinces[1] covering the period of 1980-2018[2]. We also assess whether the EEKC hypothesis, i.e., the inverted-U shaped association between economic growth and energy consumption, is present at the provincial level in China. The provincial energy consumption is measured in tons of coal equivalent per capita and calculated using data on total energy consumption and the average annual population of each province. These data are compiled from various sources such as China Statistical Yearbooks, China Energy Statistical Yearbooks, China Population Yearbooks, China Population & Employment Statistics Yearbook, and National Bureau of Statistics of China[3]. The proxy for regional economic growth is the gross regional product (GRP) per capita in the Chinese Yuan, which is obtained from different regional statistical yearbooks as well as the National Bureau of Statistics of China.

A bivariate approach to modeling the energy-growth nexus may appear underspecified. However, provincial data on other factors affecting energy us remains elusive. In addition, the versatility and all-encompassing (of economic activities) nature of GRP, like GDP, renders the inclusion of other commonly used determinants of energy consumption, such as industrial production, quite redundant. As a result, often, a bivariate approach is the only viable option for empirical modeling of regional-level energy usage, pollution, etc. Prior studies of the EEKC/EKC in Chinese provinces, including Song et al. (2008) and Li et al. (2016), have also implemented a

[1] Tibet is excluded from the econometric analysis due to insufficient data.
[2] The estimable datasets for Chongqing and Hainan are for the periods 1997-2018 and 1990-2018, respectively.
[3] http://data.stats.gov.cn/easyquery.htm?cn=E0103

bivariate approach to econometric analysis. As such, and in accordance with similar past studies such as Soytas and Sari (2003), Pao and Tsai (2010), Boden et al. (2011), and Shahbaz et al. (2016, 2017a, b), we take natural logarithmic transformations of EC and Y, and specify equation-1 as provincial energy demand function. A logarithmic transformation of the data also allows us to interpret GRP per capita as 'economic growth' and the coefficient estimates of model-1 as elasticities.

$$\ln EC_t = f(\ln Y_t) \tag{1}$$

Table-1 presents the summary statistics of the variables for each of the 30 Chinese provinces. As can be seen, the mean values of $\ln EC_t$ range between –0.430 in Guangxi to 1.201 in Shanghai. The maximum values of $\ln EC_t$ vary between 0.756 in Guanxi and 2.196 in Ningxia. The highest and lowest minimum values of $\ln EC_t$ are 0.811 (Beijing) and –2.522 (Guangdong), respectively. The measure of the variation of $\ln EC_t$, standard deviation, can be seen to range between 0.154 in Beijing to 0.928 in Guangdong. The mean value of $\ln Y_t$ is highest, at 9.956, in Shanghai and lowest in Gansu, at 8.196. $\ln Y_t$ takes maximum values between a high of 11.753 in Tianjin and a low of 10.390 in Gansu. The minimum values of $\ln Y_t$ are within the range of 4.836 in Hubei to 7.910 in Shanghai. Measuring the variation of $\ln Y_t$, its standard deviation is found to be the highest in Inner Mongolia and lowest in Shanghai, with respective values of 1.773 and 1.304. Lastly, the computed Jarque-Bera test statistics and corresponding probabilities (p-values) indicate that both variables are normally distributed in the 30 Chinese provinces at the 5% level of significance.

Table-1: Summary Statistics of Provincial Data

Province	Variable	Mean	Maximum	Minimum	Std. Dev.	Jarque-Bera**	Probability
Anhui	$\ln EC_t$	-0.182	0.759	-1.098	0.599	2.837	0.242
	$\ln Y_t$	8.342	10.704	5.673	1.559	2.373	0.305
Beijing	$\ln EC_t$	1.089	1.344	0.811	0.154	1.980	0.372
	$\ln Y_t$	9.755	11.737	7.330	1.466	3.316	0.191
Chongqing	$\ln EC_t$	0.614	1.152	-0.140	0.472	2.619	0.270
	$\ln Y_t$	8.601	11.092	6.073	1.601	2.470	0.291
Fujian	$\ln EC_t$	0.012	1.237	-1.284	0.841	3.508	0.173
	$\ln Y_t$	8.909	11.337	5.852	1.739	2.894	0.235
Gansu	$\ln EC_t$	0.340	1.135	-0.261	0.463	4.248	0.120
	$\ln Y_t$	8.196	10.390	5.905	1.454	2.682	0.262
Guangdong	$\ln EC_t$	0.055	1.042	-2.522	0.928	5.247	0.073
	$\ln Y_t$	9.118	11.294	6.176	1.626	3.005	0.223
Guangxi	$\ln EC_t$	-0.430	0.756	-1.552	0.801	3.485	0.175
	$\ln Y_t$	8.288	10.666	5.628	1.612	2.555	0.279
Hainan	$\ln EC_t$	-0.129	0.852	-1.683	0.734	1.701	0.427
	$\ln Y_t$	8.664	10.830	5.869	1.510	2.457	0.293
Hebei	$\ln EC_t$	0.569	1.426	-0.425	0.632	3.724	0.155

Table-1: Summary Statistics of Provincial Data

Province	Variable	Mean	Maximum	Minimum	Std. Dev.	Jarque-Bera**	Probability
	$\ln Y_t$	8.647	10.735	6.057	1.570	3.077	0.215
Heilongjiang	$\ln EC_t$	0.630	1.202	0.150	0.339	4.086	0.130
	$\ln Y_t$	8.800	10.723	6.542	1.387	2.913	0.233
Henan	$\ln EC_t$	0.101	0.923	-0.509	0.557	4.864	0.088
	$\ln Y_t$	8.412	10.766	5.759	1.631	2.842	0.242
Hubei	$\ln EC_t$	0.205	1.120	-0.652	0.587	3.770	0.152
	$\ln Y_t$	8.556	11.058	4.836	1.676	1.721	0.423
Hunan	$\ln EC_t$	0.036	0.928	-0.645	0.559	4.680	0.096
	$\ln Y_t$	8.463	10.877	5.900	1.604	2.645	0.266
Inner Mongolia	$\ln EC_t$	0.774	2.074	-0.416	0.888	4.537	0.103
	$\ln Y_t$	8.780	11.328	5.889	1.773	2.790	0.248
Jiangsu	$\ln EC_t$	0.366	1.374	-0.735	0.689	3.308	0.191
	$\ln Y_t$	9.147	11.587	6.293	1.703	2.754	0.252
Jiangxi	$\ln EC_t$	-0.308	0.808	-1.218	0.615	3.606	0.165
	$\ln Y_t$	8.349	10.718	5.835	1.575	2.655	0.265
Jilin	$\ln EC_t$	0.567	1.417	-0.153	0.401	1.685	0.431
	$\ln Y_t$	8.739	11.037	6.098	1.563	2.497	0.287
Liaoning	$\ln EC_t$	1.013	1.680	0.494	0.401	4.139	0.126
	$\ln Y_t$	9.101	11.275	6.023	1.527	2.192	0.334
Ningxia	$\ln EC_t$	0.889	2.196	-0.551	0.842	3.084	0.214
	$\ln Y_t$	8.521	10.867	6.071	1.567	2.646	0.266
Qinghai	$\ln EC_t$	0.692	2.080	-0.945	0.857	1.896	0.387
	$\ln Y_t$	8.526	10.841	6.129	1.504	2.432	0.296
Shaanxi	$\ln EC_t$	0.122	1.210	-0.753	0.646	4.051	0.132
	$\ln Y_t$	8.455	11.007	5.811	1.667	2.502	0.286
Shandong	$\ln EC_t$	0.378	1.393	-0.777	0.730	3.767	0.152
	$\ln Y_t$	8.912	11.259	5.996	1.676	2.838	0.242
Shanghai	$\ln EC_t$	1.201	1.602	0.634	0.326	3.678	0.159
	$\ln Y_t$	9.956	11.689	7.910	1.304	3.678	0.159
Shanxi	$\ln EC_t$	0.928	1.697	-0.103	0.592	2.739	0.254
	$\ln Y_t$	8.551	10.553	6.091	1.485	2.993	0.224
Sichuan	$\ln EC_t$	-0.070	0.937	-1.408	0.649	2.267	0.322
	$\ln Y_t$	8.343	10.724	5.768	1.591	2.588	0.274
Tianjin	$\ln EC_t$	1.115	1.780	0.288	0.426	2.043	0.360
	$\ln Y_t$	9.577	11.753	7.213	1.535	3.175	0.204
Xinjiang	$\ln EC_t$	0.794	2.111	-0.132	0.671	3.347	0.188
	$\ln Y_t$	8.654	10.816	6.016	1.509	2.553	0.279
Yunnan	$\ln EC_t$	-0.146	0.809	-1.308	0.693	3.015	0.221
	$\ln Y_t$	8.233	10.509	5.587	1.529	2.392	0.302
Zhejiang	$\ln EC_t$	0.224	1.325	-1.313	0.858	3.363	0.186
	$\ln Y_t$	9.163	11.425	6.155	1.700	3.105	0.212

Notes: Std. Dev. is abbreviation for standard deviation. Jarque-Bera: H_0: Normality of Variable. ** Reject H_0 if probability <0.050.

IV. Empirical Estimation Strategy

IV.I Nonparametric Unit Root Tests

We perform the Bierens (1997a) and Breitung (2002) nonparametric unit root tests to determine the stationarity properties of energy consumption ($\ln EC_t$) and economic growth ($\ln Y_t$). We use the nonparametric unit root tests as the parametric unit root tests can often fail to reject the null hypothesis (of non-stationarity) due to the presence of nonlinearities. The Bierens (1997a) unit root test estimates the following auxiliary function-2 for a variable z_t:

$$z_t - z_{t-1} = a \cdot z_{t-1} + b_1 \cdot (z_{t-1} - z_{t-2}) + \cdots + b_p \cdot (z_{t-p} - z_{t-p-1}) + b_{p+1} + b_{p+2} \cdot P_{t,1} + \cdots + b_{p+m+1} \cdot P_{t,m} + u_t \quad (2)$$

where, t is expressed as $t = p + 2, \dots, n$, u_t denotes a white noise, and $P_{t,k}$ represent the detrended Chebishev time polynomials in which $P_{t,1}$ is the standardized time t. The null hypothesis under the Bierens (1997a) test considers the variable z_t as a unit root with an intercept process:

$$a = b_{p+2} = \cdots b_{p+m+1} = 0 \quad (3)$$

while under the alternative it considers z_t as a stationarity process with a nonlinear trend: $a < 0$. We also perform the nonparametric unit root test developed by Breitung (2002) to verify whether the results provided by the Bierens (1997a) unit root test are robust. The advantage of Breitung (2002) procedure is that it can handle nonlinearity as well as structural changes in the time series. Breitung (2002) nonparametric unit root test can be explained by considering the following unit root process:

$$y_t = y_{t-1} + u_t \quad (4)$$

for $t = 1, \dots, n$, and u_t is a zero-mean stationary process. The following partial sums are computed as:

$$Y_t = y_1 + y_2 + \cdots + y_t \quad (5)$$

followed by the ratio of equation-6:

$$B_n = \frac{\frac{[Y_1^2 + Y_2^2 + \cdots + Y_n^2]}{n^2}}{\frac{[y_1^2 + y_2^2 + \cdots + \; y_n^2]}{n}} \qquad (6)$$

Breitung (2002) unit root test specifies virtually identical null and alternative hypotheses as that of Bierens (1997a) approach, which are outlined as follows:

H_0: y_t is a unit root with an intercept process

H_1: y_t is a trend stationary process

IV.II Nonparametric Cointegration Tests

Any presence of nonstationary variables as detected by unit root tests warrants testing for cointegration or long-run equilibrium. Here too, the parametric cointegration test procedures often fail to provide accurate results due to the presence of structural breaks and/or other sources of nonlinearities in the data-generating process. Against this backdrop, we perform Bierens (1997b) and Pedroni et al. (2015) nonparametric cointegration testing approaches, which are capable of accounting for nonlinearity in cointegrating vector to verify the long-run equilibrium in the model. Bierens (1997b) cointegration approach is a time-series cointegration rank test, which is determined by identifying two random matrices, in equation-7, from the specified empirical model-1:

$$\begin{matrix} A_m \\ B_m + c\left[\frac{A_m^{-1}}{n^2}\right] \end{matrix} \qquad (7)$$

where $m \geq q$, m is a natural number, and q is the number of variables in the model. The empirical time series model's weighted averages are denoted as y_t and $y_t - y_{t-1}$, and the outer products of these weighted averages can be summed up as matrices A and B. The eigenvectors of these two matrices are then used to compute the test statistic: λ_{min}, which is the ordered solution of the generalized eigenvalue. The hypothesized null is of zero cointegration rank ($r = 0$), while the alternative hypothesis is a rank of at least 1 ($r \geq 1$). The cointegration analysis is then extended by the panel nonparametric cointegration test of Pedroni et al. (2015). The Pedroni et al. (2015) method is also a rank test for panel cointegration. However, it tests the number of 'cross-unit' cointegration ($c =$?), i.e., the number of cross-sections (provinces) that are cointegrated with each other in the panel. This allows us to see the cross-unit cointegration of each variable–ln EC_t and ln Y_t–as well as the energy-growth model-1: $\ln EC_t = f(\ln Y_t)$. In addition, it also acts as a robustness check for the Bierens (1997b) cointegration, verifying any presence of cointegration across cross-sections and within the panel dataset of 30 Chinese provinces. Furthermore, Pedroni et al. (2015) test allows us to determine whether there is convergence–due to cross-unit cointegration–with regards to either energy consumption, economic growth, or both.

Under Pedroni et al. (2015) approach, a terminal cointegration rank (i.e., $c = N(= 30)$) is assumed by the null hypothesis against the alternative of rank lesser than under the null ($c_1 < N$). In addition to this innovative characteristic, the panel cointegration test by Pedroni et al. (2015) can account for dependence amongst cross-sections, as well as any interplay across them. Furthermore, unlike other nonparametric estimators, Pedroni (2015) approach's power is greater, and there is no need for the bandwidth or lag lengths to be elected *a-priori*. For the test statistic, Pedroni et al. (2015) modified the inverse of Breitung's (2002) time-series $\hat{\varrho}_T$ statistic, which is denoted as the *MIB* in equation-8:

$$MIB = 2T \sum_{i=1}^{N} \hat{\lambda}_i \tag{8}$$

Pedroni et al. (2015) aptly named this modified test statistic as the following *MMIB* statistic. In equation-9, $\hat{\lambda}_i$ denotes the eigenvalues of $\hat{\lambda}_{N-c+1}$ to $\hat{\lambda}_N$ whereas T symbolizes the maximum time period for each cross-section:

$$MMIB = 2T \sum_{i=N-c+1}^{N} \hat{\lambda}_i \tag{9}$$

IV.III Nonparametric Regression Estimates

The long-run correlation between $\ln EC_t$ and $\ln Y_t$ needs to be estimated if cointegration is detected in each province. To that end, we implement the nonparametric kernel smoothing regression to estimate the long-run relationship between energy consumption and economic growth. The nonparametric local linear regression estimators allow the data to determine the functional form: that is, whether to fit (or smooth) a linear or a nonlinear regression line through the data. Such methods can estimate complex nonlinear models such as higher-order polynomial functions and those involving structural breaks, which are characteristic of the EEKC hypothesis (Wagner 2015, Shahbaz et al. 2017a). Nevertheless, the nonparametric estimators retain the ability to smooth linear regressions. The scalar coefficients smoothed by these nonparametric local linear regressions are an average of the (first) derivative, or slope/gradient, smoothed for each $\ln EC_t$ and $\ln Y_t$ observation pair, and represent the average or overall effect of the latter on the former.

Since a standard nonparametric kernel smoothing regression is limited to reporting the average effect of $\ln Y_t$ on $\ln EC_t$, it is, thus, inappropriate for substantiating the EEKC hypothesis between economic growth and energy consumption. We overcome this by applying Li and Racine's (2004) CVLL nonparametric regression to examine the shape of $\ln EC_t = f(\ln Y_t)$ for each province. Like standard nonparametric kernel smoothers, it allows the data to determine the functional form (shape). In addition, the CVLL nonparametric approach smoothens the gradient vector of each regressor: $\beta(x)$, and presents it as a plot of $\ln EC_t$ against $\ln Y_t$. An estimation of the gradient requires decomposing the specified empirical model as equation-10:

$$y_j = g(x_j) + u_j, \qquad j = 1, \ldots, n \tag{10}$$

The nonparametric estimator under the CVLL approach, $\delta(x)$, is implemented using the cross-validation selections of $(\hat{h} = \hat{h}_1, \ldots, \hat{h}_q)$, by the following formula:

$$\hat{\delta}(x) = \begin{pmatrix} \hat{g}(x) \\ \hat{\beta}(x) \end{pmatrix} = \left[\sum_{i=1}^{n} W_{\hat{h},ix} \begin{pmatrix} 1 & (x_i - x)' \\ x_i - x, & (x_i - x)(x_i - x)' \end{pmatrix}\right]^{-1} \sum_{i=1}^{n} W_{\hat{h},ix} \begin{pmatrix} 1 \\ x_i - x \end{pmatrix} y_i \tag{11}$$

where

$$W_{\hat{h},ix} = \Pi_{s=1}^{q} \hat{h}_s^{-1} w\left(\frac{x_{is} - x_s}{\hat{h}_s}\right) \tag{12}$$

and $g(x)$ is estimated by equation-13:

$$\hat{g}(x) = e_1' \hat{\delta}(x) \tag{13}$$

Here, e_1 is a $(q + 1) \times 1$ vector whose first element is 1, while all other elements amount to zero (0).

IV.IV Nonparametric Granger Causation Tests

The presence of cointegration in the nonlinear context also mandates the testing of the direction of Granger causality between energy consumption and economic growth. We apply the nonparametric techniques of Hiemstra-Jones (1994) and Diks-Panchenko (2006) to test for the direction of nonlinear Granger causality between the variables by using a bivariate setting. Contrarily, conventional (parametric) Granger causality tests may incorrectly reject the null hypothesis (of non-causation) due to nonlinearities. The Hiemstra-Jones (1994) approach tests for the direction of nonlinear causality between two-time series variables, $\{X_t\}$ and $\{Y_t\}$, and involves evaluating the following null hypothesis:

$$\frac{f_{X,Y,Z}(x,y,z)}{f_Y(y)} = \frac{f_{X,Y}(x,y)}{f_Y(y)} \cdot \frac{f_{Y,Z}(y,z)}{f_Y(y)} \tag{14}$$

Where $Z_t = Y_t + 1$ and f represent the joint probability distribution function. Equation-(14) can be extended to estimate the correlation integrals $C_V(\varepsilon)$ as in equation-(15):

$$\frac{C_{X,Y,Z}(\varepsilon)}{C_{X,Y}(\varepsilon)} = \frac{C_{Y,Z}(\varepsilon)}{C_Y(\varepsilon)} \qquad \text{when } \varepsilon > 0 \tag{15}$$

These correlation integrals are estimated by the following formula:

$$C_{W,n}(\varepsilon) = \frac{2}{n(n-1)} \sum_{i<j} \sum I_{ij}^W \tag{16}$$

where

$$I_{ij}^W = I\left(\left|\left|W_i - W_j\right|\right|\right) \leq \varepsilon \tag{17}$$

The right- and left-hand side values of the sample correlation integrals from equation-(15) are tested for equality as part of the Hiemstra-Jones (1994) method.

According to Diks-Panchenko (2005, 2006), Hiemstra-Jones (1994) 'mis-specified' their null hypothesis which leads to its over-rejection. Consequently, Diks-Panchenko (2006) modified equation-(14), using a positive weight function: $g(x,y,z)$. If $g(x,y,z) = f_Y^2(y)$, the resulting null hypothesis function q can be identified as equation-(18):

$$q = E\left[f_{X,Y,Z}(X,Y,Z)f_Y(Y) - f_{X,Y}(X,Y)f_{Y,Z}(Y,Z)\right] \tag{18}$$

Here, the local density estimators of a d_W-variate random vector W at W_i is identified as:

$$\hat{f}_W(W_i) = \frac{(2\varepsilon)^{-d_W}}{n-1} \sum_{j,j \neq i} I_{ij}^W \tag{19}$$

The Diks-Panchenko (2005, 2006) test statistic is derived from equation-18 and re-formulated as equation-(20):

$$T_n(\epsilon_n) = \frac{n-1}{n(n-2)} \times \sum_{i=1}^{n} \left(\hat{f}_{X,Y,Z}(X_i, Y_i, Z_i) \hat{f}_Y(Y) - \hat{f}_{X,Y}(X_i, Y_i) \hat{f}_{Y,Z}(Y_i, Z_i) \right) \tag{20}$$

The test statistics under Hiemstra-Jones (1994) and Diks-Panchenko (2006) approaches require choosing an appropriate bandwidth, ϵ_n, based on the sample size n. Note that Diks-Panchenko (2006) argues against any empirical choice of bandwidth beyond the bounds: $[0.5, 1.5]$.

V. Empirical Results

We primarily test whether linearity is present between the variables or not. Table-2 provides the estimated test statistic and simulated p-value for the nonparametric kernel-based Hsiao et al. (2007) test for linearity applied on model-1 for each of the 30 Chinese provinces. The test statistics are unable to reject the null of linearity, at the standard significance levels, for Sichuan and Tianjin. In contrast, the test statistic rejects the null at 5% level in Shanxi and at 1% level for the remaining provinces. Accordingly, we can conclude that in Chinese provinces, with the exception of Sichuan and Tianjin, the functional form of the relationship between energy consumption and economic growth is nonlinear.

Table-2: Hsiao et al. (2007) Test for Linearity

Province	$\hat{J}_n$-statistic	*p*-value
Anhui	5.886586***	0.000000
Beijing	3.281871***	0.000000
Chongqing	1.655651***	0.007519
Fujian	3.936054***	0.000000
Gansu	5.550317***	0.000000
Guangdong	2.577342***	0.002506
Guangxi	5.691589***	0.000000
Guizhou	2.984445***	0.000000
Hainan	3.500776***	0.000000
Hebei	3.810957***	0.000000
Heilongjiang	5.569949***	0.000000
Henan	4.956317***	0.000000
Hubei	4.631561***	0.000000

Table-2: Hsiao et al. (2007) Test for Linearity

Province	$\hat{J}_n$-statistic	*p*-value
Hunan	3.898865***	0.000000
Inner Mongolia	4.782587***	0.000000
Jiangsu	4.742567***	0.000000
Jiangxi	3.866591***	0.000000
Jilin	3.351876***	0.000000
Liaoning	4.800094***	0.000000
Ningxia	3.356480***	0.000000
Qinghai	4.454670***	0.000000
Shaanxi	3.856178***	0.000000
Shandong	3.420953***	0.000000
Shanghai	4.427813***	0.000000
Shanxi	1.213408**	0.045113
Sichuan	-0.503885	0.238100
Tianjin	1.000144	0.175440
Xinjiang	4.584644***	0.000000
Yunnan	5.428832***	0.000000
Zhejiang	4.758238***	0.000000

Notes: Exogeneous term: intercept. H_0: Linearity of function. Simulated *p*-values are from 399 replications. *** Reject H_0 when *p*-value <0.010000. ** Reject H_0 when *p*-value <0.050000.

Table-3 provides the simulated p-values of the heteroskedasticity robust version of Chow ($\hat{C}$) and Hausman ($\widehat{H}$) tests performed as part of Chen-Hong (2012) procedure for testing a smooth structural change in model-1 using nonparametric regressions. This test can detect known and unknown smooth and abrupt structural changes, without forcing a rigid functional form by estimating model-1 using nonparametric kernel smoothing. The p-values are lower than 0.01 under Chow and Hausman tests in Anhui, Beijing, Gansu, Guangdong, Guangxi, Hainan, Hebei, Heilongjiang, Hunan, Jiangsu, Jiangxi, and Sichuan. These tests' statistics reject the null hypothesis of no smooth structural change in model-1 can be rejected at a 1% level in 12 provinces. In Hubei and Ningxia, the p-values fall under 0.05 for Chow and Hausman versions of Chen-Hong (2012) test, rejecting the null at 5% level of significance. The null is also rejected at 10% level in Liaoning where the simulated p-value is less than 0.10. In other regions–Guizhou, Inner Mongolia, Qinghai, Shandong, and Shanghai, the null hypothesis is rejected at different significance levels by the respective p-values of Chow and Hausman tests. In Fujian, however, the p-value for the Chow test fails to reject the null at usual significance levels (1%, 5%, and 10%) while the Hausman test rejects the null at 5% level. In the remaining nine provinces–Chongqing, Henan, Jilin, Shaanxi, Shanxi, Tianjin, Xinjiang, Yunnan, and Zhejiang, Chow and Hausman tests fail to the reject the null at any standard significance level. Accordingly, we can conclude that there is a presence of abrupt and/or smooth structural change in the function of energy consumption with respect to economic growth in 21 of 30 Chinese provinces.

In the remaining nine provinces, Chen-Hong (2012) test finds no evidence of any structural change–smooth or otherwise.

Table-3: Chen-Hong (2012) Test for Smooth Structural Change

Province	$\hat{C}$-het	$\hat{H}$-het
Anhui	0.0039003900***	0.0015001500***
Beijing	0.0022002200***	0.0010001000***
Chongqing	0.1758175800	0.1016101600
Fujian	0.1171117100	0.0126012600**
Gansu	0.0053005301***	0.0034003400***
Guangdong	0.0004000400***	0.0000000000***
Guangxi	0.0047004700***	0.0093009301***
Guizhou	0.0752075210*	0.0100010000***
Hainan	0.0000000000***	0.0000000000***
Hebei	0.0027002700***	0.0031003100***
Heilongjiang	0.0003000300***	0.0018001800***
Henan	0.2568256800	0.2692269200
Hubei	0.0185018500**	0.0207020700**
Hunan	0.0031003100***	0.0082008201***
Inner Mongolia	0.0092009201***	0.0116011600**
Jiangsu	0.0033003300***	0.0034003400***
Jiangxi	0.0010001000***	0.0021002100***
Jilin	0.4434443400	0.5060506100
Liaoning	0.0860086010*	0.0832083210*
Ningxia	0.0446044600**	0.0129012900**
Qinghai	0.0167016700**	0.0036003600***
Shaanxi	0.4128412800	0.1954195400
Shandong	0.0371037100**	0.0649064910*
Shanghai	0.0052005201***	0.0147014700**
Shanxi	0.1261126100	0.2013201300
Sichuan	0.0000000000***	0.0000000000***
Tianjin	0.3870387000	0.3988398800
Xinjiang	0.4810481000	0.3968396800
Yunnan	0.1704170400	0.1093109300
Zhejiang	0.8480848100	0.3293329300

Notes: H_0: Model is devoid of smooth structural change. $\hat{C}$-het and $\hat{H}$-het denote the generalized Chow and Hausman tests, respectively. These two tests are robust to heteroskedasticity. The bootstrap, *B*=9999, simulate the *p*-values. *** Reject H_0 when *p*-value <0.0100000000. ** Reject H_0 when *p*-value <0.0500000000. * Reject H_0 when *p*-value <0.10.

The empirical findings in Tables-2 and 3 indicate that, for all but one province, model-1 suffers from either nonlinearity, or smooth and/or abrupt structural change, or both. Tianjin is the only province which exhibits a linear functional form and a lack of any structural change. The findings of nonlinearity and structural change are unique in contrast to prior studies, such as Li et al. (2011), Zhang and Xu (2012), Zhang et al. (2018), and Dong et al. (2019), who do not conduct such tests. In such a situation, nonparametric econometric methods are more appropriate for an empirical analysis as they do not require *a-priori* assumptions that are essential for parametric estimations. Moreover, nonparametric methods are better able to model nonlinearities, including structural breaks and higher-order polynomial functions than their parametric counterparts. Furthermore, in the absence of nonlinearity, the nonparametric estimator simply allows the data to fit a linear model. This is useful for Tianjin, as the province does not appear to exhibit any of the various forms of nonlinearity. These characteristics of provincial-level data motivate the use of nonparametric methods, which allow for consistent, efficient, and comparable estimates across 30 Chinese provinces.

The empirical analysis of the energy consumption-economic growth nexus continues with the nonlinear tests for unit root. Table-4 provides the estimated test statistics and simulated p-values from the nonparametric Bierens (1997a) and Breitung (2002) unit root tests for the two model-(1) variables–$\ln EC_t$ and $\ln Y_t$–from each of 30 provinces. It can be observed that the test statistics estimated from the variables their respective level forms have p-values that exceed all the standard significance levels (1%, 5%, and 10%) in 30 Chinese provinces. The test statistics are, thus, unable to reject the null of non-stationarity, and the variables are found to contain unit-roots. The Breitung (2002) test, in particular, provides evidence that the variables are nonstationary, and that this non-stationarity is not due to any structural changes in the time series. We proceed with two unit root tests on the first differenced form of the two variables. The test statistics for Bierens (1997a) and Breitung (2002) now have p-values lower than 0.05 and reject the null in favor of the alternative for all 30 provinces. This indicates that our variables are stationary in the first difference form. Based on the two nonparametric unit root test results, we can robustly conclude that our variables are nonstationary and integrated of order 1 i.e., I(1). Therefore, we can now apply the nonparametric tests for cointegration, Granger causality, and estimate the long-run equations based on model-(1). Our findings of nonlinear unit-roots are similar to Li et al. (2011) and Zhang and Xu (2012), who performed panel unit root tests. However, other provincial studies such as Zhang et al. (2018) and Dong et al. (2019) do not test their datasets (time series and panel, respectively) for unit root.

Table-4: Bierens (1997a) and Breitung (2002) Tests for Unit Root

Province	Variable	Level		1st difference	
		Bierens	Breitung	Bierens	Breitung
Anhui	$\ln EC_t$	-12.7281(0.6200)	0.0140(0.3000)	-29.9916(0.0300)**	0.0045(0.0000)**
	$\ln Y_t$	-4.6858(0.7800)	0.0058(0.2000)	-28.9741(0.0400)**	0.0024(0.0000)**
Beijing	$\ln EC_t$	1.2614(0.9800)	0.0172(0.6000)	-42.4007(0.0400)**	0.0050(0.0000)**
	$\ln Y_t$	2.6272(1.0000)	0.0205(0.9000)	-31.7766(0.0300)**	0.0054(0.0000)**
Chongqing	$\ln EC_t$	-29.0977(0.2900)	0.0119(0.4000)	-94.6050(0.0300)**	0.0063(0.0000)**
	$\ln Y_t$	-17.6636(0.3300)	0.0035(0.1500)	-24.3767(0.0300)**	0.0029(0.0400)**
Fujian	$\ln EC_t$	-12.0106(0.5700)	0.0119(0.8000)	-28.4405(0.0000)**	0.0056(0.0000)**
	$\ln Y_t$	-4.5166(0.7700)	0.0193(0.9000)	-21.5826(0.0300)**	0.0030(0.0000)**
Gansu	$\ln EC_t$	-4.3774(0.9300)	0.0207(1.0000)	-27.3804(0.0100)**	0.0043(0.0000)**
	$\ln Y_t$	-19.5094(0.1800)	0.0053(0.3000)	-23.6181(0.0350)**	0.0035(0.0000)**
Guangdong	$\ln EC_t$	-5.4043(0.7300)	0.0157(0.5000)	-29.3127(0.0400)**	0.0048(0.0000)**
	$\ln Y_t$	-1.9592(0.8900)	0.0218(1.0000)	-30.3636(0.0325)**	0.0034(0.0000)**

Table-4: Bierens (1997a) and Breitung (2002) Tests for Unit Root

Province	Variable	Level		1st difference	
		Bierens	Breitung	Bierens	Breitung
Guangxi	$\ln EC_t$	-29.9000(0.3300)	0.0117(0.6000)	-22.1917(0.0300)**	0.0060(0.0000)**
	$\ln Y_t$	-18.1406(0.3000)	0.0099(0.4000)	-375.8493(0.0463)**	0.0042(0.0000)**
Guizhou	$\ln EC_t$	-7.1989(0.7550)	0.0102(0.5000)	-49.2059(0.0400)**	0.0045(0.0333)**
	$\ln Y_t$	-7.6498(0.6700)	0.0132(0.6000)	-23.6296(0.0340)**	0.0032(0.0000)**
Hainan	$\ln EC_t$	-4.5644(0.7300)	0.0115(0.5000)	-39.3035(0.0000)**	0.0044(0.0000)**
	$\ln Y_t$	-47.8641(0.1200)	0.0047(0.3000)	-568.5295(0.0300)**	0.0004(0.0000)**
Hebei	$\ln EC_t$	-14.0164(0.4600)	0.0083(0.3333)	-22.3841(0.0250)**	0.0036(0.0000)**
	$\ln Y_t$	-3.8411(0.7600)	0.0172(0.8000)	-18.3709(0.0400)**	0.0048(0.0000)**
Heilongjiang	$\ln EC_t$	-3.9569(0.7800)	0.0144(0.6000)	-50.7624(0.0100)**	0.0038(0.0000)**
	$\ln Y_t$	-9.9413(0.4900)	0.0142(0.8000)	-717.1599(0.0200)**	0.0040(0.0000)**
Henan	$\ln EC_t$	-11.5636(0.3700)	0.0120(0.5000)	-35.2965(0.0350)**	0.0017(0.0000)**
	$\ln Y_t$	-19.3150(0.2500)	0.0102(0.5000)	-1209.5087(0.0100)**	0.0047(0.0333)**
Hubei	$\ln EC_t$	-10.9594(0.5500)	0.0107(0.3000)	-25.0688(0.0420)**	0.0038(0.0000)**
	$\ln Y_t$	-7.2685(0.6800)	0.0045(0.8000)	-1771.9743(0.0100)**	0.0004(0.0000)**
Hunan	$\ln EC_t$	-8.4780(0.6100)	0.0112(0.5000)	-25.4739(0.0300)**	0.0038(0.0000)**
	$\ln Y_t$	-24.8781(0.1600)	0.0057(0.2000)	-413.3709(0.0100)**	0.0048(0.0000)**
Inner Mongolia	$\ln EC_t$	-6.4208(0.8100)	0.0140(0.8000)	-34.7117(0.0100)**	0.0046(0.0000)**
	$\ln Y_t$	-18.4933(0.2600)	0.0068(0.2000)	-259.5942(0.0200)**	0.0048(0.0000)**
Jiangsu	$\ln EC_t$	-10.0441(0.5400)	0.0112(0.4000)	-32.9061(0.0300)**	0.0055(0.0000)**
	$\ln Y_t$	-5.9411(0.6900)	0.0144(0.7000)	-33.5989(0.0000)**	0.0037(0.0000)**
Jiangxi	$\ln EC_t$	-3.3945(0.9200)	0.0191(1.0000)	-29.8204(0.0100)**	0.0039(0.0000)**
	$\ln Y_t$	-22.7459(0.1900)	0.0073(0.4000)	-19.7395(0.0400)**	0.0047(0.0000)**
Jilin	$\ln EC_t$	-3.1617(0.9100)	0.0075(0.3000)	-34.7618(0.0383)**	0.0041(0.0000)**
	$\ln Y_t$	-22.0852(0.1650)	0.0065(0.3000)	-33.9103(0.0375)**	0.0029(0.0000)**
Liaoning	$\ln EC_t$	-11.1217(0.5300)	0.0129(0.5000)	-29.1438(0.0100)**	0.0048(0.0000)**
	$\ln Y_t$	-19.1369(0.3300)	0.0066(0.8000)	-810.5544(0.0363)**	0.0006(0.0000)**
Ningxia	$\ln EC_t$	-4.6993(0.8800)	0.0114(0.6000)	-43.1974(0.0200)**	0.0038(0.0000)**
	$\ln Y_t$	-15.9031(0.2800)	0.0056(0.2000)	-25.3869(0.0300)**	0.0038(0.0429)**
Qinghai	$\ln EC_t$	-5.3312(0.8200)	0.0115(0.5000)	-258.3354(0.0000)**	0.0043(0.0000)**
	$\ln Y_t$	-10.3852(0.5100)	0.0059(0.2000)	-26.7139(0.0200)**	0.0034(0.0000)**
Shaanxi	$\ln EC_t$	-7.6012(0.8600)	0.0185(1.0000)	-23.1137(0.0350)**	0.0035(0.0000)**
	$\ln Y_t$	-16.7947(0.2800)	0.0058(0.2000)	-19.6927(0.0300)**	0.0045(0.0000)**
Shandong	$\ln EC_t$	-10.3444(0.6500)	0.0082(0.2000)	-26.7581(0.0300)**	0.0044(0.0250)**
	$\ln Y_t$	-8.3464(0.5600)	0.0164(0.7000)	-625.8048(0.0200)**	0.0042(0.0000)**
Shanghai	$\ln EC_t$	0.4931(0.9600)	0.0158(0.7000)	-28.8662(0.0050)**	0.0043(0.0000)**
	$\ln Y_t$	-3.3112(0.8600)	0.0182(0.6000)	-327.2537(0.0200)**	0.0033(0.0000)**
Shanxi	$\ln EC_t$	-22.1533(0.4100)	0.0076(0.4000)	-196.3888(0.0000)**	0.0007(0.0000)**
	$\ln Y_t$	-13.1601(0.4200)	0.0091(0.6000)	-23.4347(0.0300)**	0.0040(0.0000)**
Sichuan	$\ln EC_t$	-52.3770(0.1867)	0.0164(1.0000)	-3831.0354(0.0000)**	0.0003(0.0000)**
	$\ln Y_t$	-16.7342(0.3400)	0.0071(0.3000)	-194.3471(0.0275)**	0.0049(0.0000)**
Tianjin	$\ln EC_t$	-16.8077(0.1450)	0.0091(0.2000)	-117.4881(0.0380)**	0.0014(0.0000)**
	$\ln Y_t$	-64.1587(0.1625)	0.0095(0.3000)	-15000.4185(0.0000)**	0.0048(0.0333)**
Xinjiang	$\ln EC_t$	-4.2421(0.9800)	0.0185(1.0000)	-50.3222(0.0100)**	0.0012(0.0000)**
	$\ln Y_t$	-0.5605(0.9700)	0.0183(0.9000)	-32.5853(0.0400)**	0.0023(0.0000)**
Yunnan	$\ln EC_t$	-8.1506(0.7700)	0.0068(0.2000)	-29.1545(0.0400)**	0.0037(0.0000)**
	$\ln Y_t$	-7.3773(0.6800)	0.0163(0.9000)	-21.8191(0.0417)**	0.0037(0.0000)**
Zhejiang	$\ln EC_t$	-17.5203(0.2600)	0.0113(0.7000)	-23.7544(0.0400)**	0.0029(0.0300)**
	$\ln Y_t$	-4.6492(0.7100)	0.0207(0.9000)	-31.1835(0.0400)**	0.0037(0.0000)**

Notes: *p*-values are in parentheses. H_0: Series is nonstationary with an intercept. H_1: Series is a nonlinear trend stationary process.
Bierens (1997a): Test statistic = $\hat{A}m$; *p*-values are simulated for the relevant sample size using 100 replications.
Breitung (2002): *p*-values are simulated for the relevant sample size using 10 replications.
** Reject H_0 if *p*-value < 0.05.

Table-5 provides the respective null hypothesis (H_0), estimated test statistic (λ_{min}), 5% level critical values, and cointegration rank (r) from the Bierens (1997b) cointegration test performed on model-(1) for each Chinese province. As can be seen, the null of zero cointegrating equation ($r = 0$) is rejected as the relevant test statistic fall below the corresponding critical value at the 5% level for each of 30 provinces. The null of one cointegrating equation ($r = 1$) cannot be rejected as the respective test statistics exceed the corresponding 5% level critical values in every province. As such, we can conclude that model-(1) has a nonlinear cointegration rank of one ($r = 1$) for all 30 Chinese provinces according to the Bierens (1997b) test results.

Table-5: Bierens (1997b) Test for Cointegration

Province	H_0	m=?	Test statistic (λ_{min})	Critical value (α=5%)	Rank, r=?
Anhui	r=0	3	0.00398**	0.017	
	r=1	2	0.12943	0.054	1
Beijing	r=0	3	0.00419**	0.017	
	r=1	2	1.41643	0.054	1
Chongqing	r=0	3	0.00106**	0.017	
	r=1	2	0.46724	0.054	1
Fujian	r=0	3	0.00143**	0.017	
	r=1	2	1.75733	0.054	1
Gansu	r=0	3	0.01505**	0.017	
	r=1	2	0.13243	0.054	1
Guangdong	r=0	3	0.00510**	0.017	
	r=1	2	8.24578	0.054	1
Guangxi	r=0	3	0.00101**	0.017	
	r=1	2	0.33085	0.054	1
Guizhou	r=0	3	0.00455**	0.017	
	r=1	2	0.61089	0.054	1
Hainan	r=0	3	0.00213**	0.017	
	r=1	2	0.71628	0.054	1
Hebei	r=0	3	0.00365**	0.017	
	r=1	2	3.12234	0.054	1
Heilongjiang	r=0	3	0.00590**	0.017	
	r=1	2	0.55596	0.054	1
Henan	r=0	3	0.00472**	0.017	
	r=1	2	1.67832	0.054	1
Hubei	r=0	3	0.00941**	0.017	
	r=1	2	1.88282	0.054	1
Hunan	r=0	3	0.00368**	0.017	
	r=1	2	2.76910	0.054	1
Inner Mongolia	r=0	3	0.00720**	0.017	
	r=1	2	1.06180	0.054	1
Jiangsu	r=0	3	0.00340**	0.017	
	r=1	2	5.07284	0.054	1
Jiangxi	r=0	3	0.00420**	0.017	
	r=1	2	2.03105	0.054	1
Jilin	r=0	3	0.01644**	0.017	
	r=1	2	0.74532	0.054	1
Liaoning	r=0	3	0.00227**	0.017	

Table-5: Bierens (1997b) Test for Cointegration

Province	H_0	m=?	Test statistic (λ_{min})	Critical value (α=5%)	Rank, r=?
	r=1	2	1.82936	0.054	1
Ningxia	r=0	3	0.00889**	0.017	
	r=1	2	1.42593	0.054	1
Qinghai	r=0	3	0.00724**	0.017	
	r=1	2	1.89782	0.054	1
Shaanxi	r=0	3	0.01120**	0.017	
	r=1	2	0.85530	0.054	1
Shandong	r=0	3	0.00925**	0.017	
	r=1	2	3.12205	0.054	1
Shanghai	r=0	3	0.00426**	0.017	
	r=1	2	1.52941	0.054	1
Shanxi	r=0	3	0.01334**	0.017	
	r=1	2	1.03553	0.054	1
Sichuan	r=0	3	0.00023**	0.017	
	r=1	2	0.19327	0.054	1
Tianjin	r=0	3	0.00266**	0.017	
	r=1	2	0.28505	0.054	1
Xinjiang	r=0	3	0.00025**	0.017	
	r=1	2	1.24426	0.054	1
Yunnan	r=0	3	0.00253**	0.017	
	r=1	2	1.31895	0.054	1
Zhejiang	r=0	3	0.00357**	0.017	
	r=1	2	1.68362	0.054	1

Notes: Exogenous term: intercept. Rank, r is the number of cointegrating vectors. ** Reject H_0 at the 5% level of significance if test statistic < the 5% critical value.

Table-6 displays the estimated test statistics and corresponding critical value at the 5% level of significance from Pedroni et al. (2015). This procedure tests for cross-unit cointegration in energy consumption, economic growth, across the different Chinese provinces. This allows us to observe the long-run equilibrium in each variable and gauge any possible convergence in energy consumption and economic growth patterns in the Chinese provinces. Panel-A exhibits the test for cross-unit cointegration for energy consumption $\ln EC_t$ across 30 provinces. The estimated test statistic ($MMIB$) exceeds the critical value at the 5% level. This results in the rejection of the null hypothesis of 30 cointegrated cross-sections ($c = 30$). The sequential rank test finds a cointegration rank of 26 ($c = 26$), meaning there is a long-run equilibrium in energy consumption patterns across 26 of the 30 provinces[4]. This allows us to argue in favor of convergence in energy usage across the majority of China's provinces. As various provinces in development, economic growth is to meet the needs of the people for survival and development. Energy consumption is the necessary condition for

[4] The list of these cointegrated provinces is indeterminate from the Pedroni et al. (2015) test procedure. It may be possible to determine which provinces are non-convergent, but this would not yield enough insight into the matter and would unduly lengthen our discussion.

sustaining the continuous operation of the regional economy and basic carrier for meeting production and living needs. Therefore, provinces are bound to improve the quality of economic development by adjusting and optimizing the industrial structure and improving energy efficiency, thereby achieving the convergence of energy consumption among Chinese provinces.

Panel-B (Table-6) provides the Pedroni et al. (2015) estimates for provincial economic growth ($\ln Y_t$). Here too, the test statistic is greater than the corresponding 5% level critical value, thereby rejecting the null of full cross-unit cointegration ($c = 30$). However, the sequential trace test of Pedroni et al. (2015) procedure finds a cross-unit cointegration rank of 27 ($c = 27$), indicating that economic growth patterns are converging in most of the Chinese provinces. With the continuous deepening of China's reform and opening up, especially the acceleration of the marketization process, the quality and efficiency of China's provincial economic growth have been significantly improved. The rational allocation of production factors such as capital and labor under the guidance of market mechanisms has greatly improved social production efficiency and reduced the economic growth gap between provinces. As a result, there has been a convergence in economic growth patterns in Chinese provinces. Panel-C of Table-6 presents cross-unit cointegration test results for model-(1). The null of rank ($c = 30$) is rejected due to the estimated test statistic exceeding the critical value (at 5% level) in magnitude. Further, the sequential trace test indicates cross-unit cointegration in 23 of 30 provinces, i.e., $c = 23$. While the rank is lower than for individual variables, this demonstrates convergence in the nexus between energy consumption and economic growth in the majority of Chinese provinces. It also provides further evidence of long-run equilibrium in the energy-growth nexus across most of the 30 Chinese provinces. The evidence of nonlinear long-run equilibrium in the energy-growth nexus in our empirical analysis resembles that of Li et al. (2011) and Zhang and Xu (2012) who performed panel cointegration tests, but not Zhang et al. (2018) and Dong et al. (2019) who did not perform such tests.

Table-6: Pedroni et al. (2015) Test for Panel Cointegration

Panel A: Cross unit cointegration of $\ln EC_t$	
Indicator	Value
Test statistic ($MMIB$)	78,332**
Critical value (α=5%)	57,032
Sequential $MMIB$ Rank (c=?)	26
Panel B: Cross unit cointegration of $\ln Y_t$	
Indicator	Value
Test statistic ($MMIB$)	74,976**
Critical value (α=5%)	57,032
Sequential $MMIB$ Rank (c=?)	27
Panel C: Cross unit cointegration of $\ln EC_t = f(\ln Y_t)$	
Indicator	Value

Table-6: Pedroni et al. (2015) Test for Panel Cointegration

Test statistic ($MMIB$)	211,296**
Critical value (α=5%)	155,348
Sequential $MMIB$ Rank (c=?)	23

Notes: Exogenous term: intercept. c refers to the number of cointegrated cross-sections. H_0: $c = 30$ vs. H_1: $c_1 < 30$. The critical values are estimated by the response surface regressions. ** Reject H_0 if test statistic > 5% critical value.

Table-7 provides the provincial effect estimates as well as the corresponding standard error, p-value, effect bandwidth, and R^2 from the nonparametric local linear regressions performed on model-(1) for each province. The estimated effect represents the average of the gradient (or derivatives) of $\ln EC_t$ with respect to $\ln Y_t$ for each province. The effect estimates are statistically significant at the 1% level of significance in 24 of 30 Chinese provinces. The effect estimates are significant at the 5% level in Heilongjiang and Ningxia, and at the 10% level in Beijing, Henan, Hunan, and Tianjin. The effect estimates can be interpreted as the implied nonlinear elasticity of energy consumption with respect to economic growth, averaged for all values of both variables in the respective province. As an example, the effect estimate of 0.3603 in Anhui implies that a 1% increase in economic growth results in an average of some 0.36% increase in energy consumption. The largest elasticity value of 0.7802 is registered in Hainan, while the smallest value of –0.0995 is seen in Beijing. The reason is that the secondary industry with high energy consumption and low added value has a lower proportion in Beijing, and tertiary industry with low energy consumption and high added value accounts for a larger proportion. A positive relationship (linear as well as threshold) between energy consumption and economic growth in Chinese provinces has been noted by Li et al. (2011), Zhang and Xu (2012), and Dong et al. (2019). A negative relationship between such variables is observed, especially in Beijing, by Zhang et al. (2018).

The estimated nonparametric local linear regression estimates exhibit very good fits with the respective R^2 values higher than 0.95 for the lion's share of the provinces. The highest R^2 value, at 0.9996, is found for Jiangsu while the lowest, at 0.6936, is recorded for Sichuan. The bandwidths used in smoothing the nonparametric local linear regressions are less 0.5 for most provinces, with the exceptions being Hubei, Jilin, and Sichuan. This implies the estimator did not require over-smoothing of kernel density functions for the majority of 30 Chinese provinces.

Table-7: Nonparametric Local Linear Regression Estimates

	Model: $\ln EC_t = f(\ln Y_t)$				
Province	Effect ($\ln Y_t$) estimate	Effect std. err.	Effect p-value	Effect bandwidth	R^2
Anhui	0.3603***	0.0345	0.0000	0.2264	0.9995
Beijing	-0.0995*	0.0552	0.0710	0.2483	0.9487
Chongqing	0.4696***	0.0995	0.0000	0.4832	0.9218

Table-7: Nonparametric Local Linear Regression Estimates

Province	Model: $\ln EC_t = f(\ln Y_t)$				
	Effect ($\ln Y_t$) estimate	Effect std. err.	Effect p-value	Effect bandwidth	R^2
Fujian	0.5196***	0.0676	0.0000	0.2500	0.9984
Gansu	0.3116***	0.0395	0.0000	0.1931	0.9984
Guangdong	0.6778***	0.1429	0.0000	0.2006	0.9988
Guangxi	0.4263***	0.0625	0.0000	0.1654	0.9994
Guizhou	0.5258***	0.0967	0.0000	0.1865	0.9982
Hainan	0.7802***	0.1083	0.0000	0.2929	0.9974
Hebei	0.3113***	0.1002	0.0020	0.1559	0.9985
Heilongjiang	0.1582**	0.0705	0.0250	0.1564	0.9969
Henan	0.2652*	0.1533	0.0840	0.1604	0.9945
Hubei	0.3331***	0.0306	0.0000	1.1628	0.9710
Hunan	0.2354*	0.1239	0.0570	0.1515	0.9939
Inner Mongolia	0.3518***	0.0918	0.0000	0.1607	0.9983
Jiangsu	0.3728***	0.0574	0.0000	0.1822	0.9996
Jiangxi	0.4899***	0.0961	0.0000	0.1425	0.9986
Jilin	0.4263***	0.0344	0.0000	5319258	0.9288
Liaoning	0.2297***	0.0391	0.0000	0.6233	0.9802
Ningxia	0.6889**	0.2723	0.0110	0.1425	0.9980
Qinghai	0.6508***	0.1010	0.0000	0.2361	0.9960
Shaanxi	0.3519***	0.1000	0.0000	0.1538	0.9980
Shandong	0.3672***	0.1199	0.0020	0.1788	0.9961
Shanghai	0.1813***	0.0488	0.0000	0.1733	0.9973
Shanxi	0.3738***	0.0404	0.0000	0.4330	0.9704
Sichuan	0.3388***	0.0463	0.0000	2.4843	0.6936
Tianjin	0.1465*	0.0815	0.0720	0.2563	0.9699
Xinjiang	0.5059***	0.1394	0.0000	0.1615	0.9960
Yunnan	0.4363***	0.0614	0.0000	0.2336	0.9978
Zhejiang	0.4848***	0.0602	0.0000	0.1821	0.9994

Notes: Std. err. refers to the standard error of effect estimates. These are robust standard errors simulated by 100 bootstrap replications. Effect estimates are averages of derivatives of the regressor in question. The kernel is Epanechnikov and the bandwidth is based on cross validation. ***, **, & * represent statistical significance of effect estimates at 1%, 5%, & 10% levels, respectively.

Figure-1 presents the plots of the estimated CVLL regressions for model-(1) from each province. The plot depicts the dynamic and/or nonlinear relationship between energy consumption and economic growth in the respective provinces. The shape of the plot allows us to determine whether the energy Kuznets curve holds in a particular province. A quick inspection indicates the S-shape, in its many variations, describes the relationship between economic growth and energy consumption in the majority of Chinese provinces. The S-shape is particularly evident in Chongqing, Fujian, Gansu, Hainan, Hebei, Heilongjiang, Inner Mongolia, Jiangsu, Jiangxi, Jilin, Qinghai, Shaanxi, Shandong, Yunnan, and Zhejiang. The probable reason is that these provinces had a relatively low level of economic development at the early stage, and energy consumption was mainly used to maintain basic living needs. With the upgrading of industrial structure, the secondary industry represented by the manufacturing industry occupied a dominant position. At this stage, energy consumption has increased rapidly with economic growth. After a period of high-speed industrialization, the proportion of tertiary industry providing financial security, technical support, and support services for the industry has increased significantly. When industrialization enters into the mature stage, the economy develops to a higher level. With the replacement of high-energy-consumption secondary industries by low-energy-consumption tertiary industries, energy consumption will remain at a certain level, which may then show a slow decline. Therefore, there is an S-shaped relationship between economic growth and energy consumption. In provinces including Anhui, Guangxi, and Shanxi, the S-shape is faint but apparent in their respective plots. This may be due to the relatively weak level of economic development of these provinces, and the relationship between economic growth and energy consumption in different periods is not strong. In others, such as Hubei and Ningxia, a hybridized version of an S-shaped association between energy consumption and economic growth can be observed. Economic development levels of such provinces fluctuate greatly, so the relationship between economic growth and energy consumption is more complicated. The estimated model-(1) in Hubei has an S-shape with a 'kinky' trough with respect to $\ln Y_t$ value at slightly under 6, giving an appearance of a 'U+S' shaped association between the two variables. This may be due to heavy industry development in Hubei Province at an early stage of development and the reduction of heavy industry development at a later stage. Therefore, an inverted U-shaped curve appears between economic growth and energy consumption at an early stage of economic development. In Liaoning, however, the S-shape appears to be supplemented by a W-shape for the low values of economic growth ($\ln Y_t$). Liaoning is a heavy industry province dominated by secondary industry. The relationship between economic growth and energy consumption is closely linked to the exploitation of fossil energy. With the continuous upgrading of industrial structure, a W-shaped fluctuation state is shown between economic growth and energy consumption.

A more complex relationship between energy consumption and economic growth can be observed in other provinces. An M-shape between economic growth and energy consumption is apparent in Hunan, Ningxia, and Tianjin. The industrial structure of these provinces has changed greatly, so an M-shape is present between economic growth and energy consumption. The only instance of an independent W-shape is found in Henan. This is probably due to the significant changes in the industrial structure of Henan Province, and the gradual transition from agriculture to resource-based industries. Beijing exhibits a complex nexus between energy consumption and economic growth with multiple instances of an inverted U-shape with respect to higher values of $\ln Y_t$. Before the concept of ecological civilization construction was put forward, Beijing's economic growth was accompanied by fluctuating energy consumption. The most prominent inverted U-shape in Beijing occurs when $\ln Y_t$ exceeds ~10.5 in magnitude. The multiple instances of an inverted U-shape in Beijing are perhaps behind the average negative effect of economic growth on energy consumption in the province. With the emphasis on the ecological environment, clean energy production has significantly reduced energy consumption, while economic growth remains strong.

The more traditional shapes can be found in the remaining five Chinese provinces. The nexus between energy use and economic growth is U-shaped in Xinjiang, while it is inverted U-shaped in Guangdong, Guizhou, and Shanghai. The U-shape relationship in Xinjiang may be due to the relatively slow development of Xinjiang exhibiting a gradual increase in energy consumption as the economy grows, but the ecological environmental protection has not yet been paid attention to. While the other three provinces have proposed the concept of ecological civilization construction, while realizing economic growth, they also pay attention to reducing energy consumption to achieve coordinated development of economy and ecological environment. Sichuan remains the only province where the relationship between economic growth and energy consumption is an upward sloping straight line. This may be because Sichuan has always been a tourism-oriented development model, and the relationship between economic growth and energy consumption is relatively stable. Similar to the average effects estimates from the local linear regressions in Table-7, the estimated CVLL regression plots exhibit very good fits, as all, but one province (Sichuan), provinces have respective R^2 in excess of 0.95. The highest value of R^2 is recorded in Jiangsu at 1.000 while the lowest is recorded in Sichuan at 0.689. In addition, the bandwidths employed for estimating the CVLL regressions are all less than 0.5, with the exception of Sichuan. This implies that the nonparametric CVLL estimator, like the local linear estimator in Table-7**Table-7**, did not over-smooth the kernel density function. These attributes of the CVLL results are virtually identical to that of local linear regressions from Table-7.

In determining the presence of the EEKC, we look for a visible inverted U-shaped relationship between energy consumption and economic growth. The inverted U-shape may stand independently or be contained–but will be clearly visible with the curve bending downwards–within the more complex shapes such as S, M, W, and multiple inverted U's. Based on these criteria, we find visible evidence of EEKC hypothesis in a total of 20 provinces, namely Beijing, Chongqing, Guangdong, Guizhou, Hebei, Heilongjiang, Henan, Hubei, Hunan, Inner Mongolia, Jiangsu, Jiangxi, Jilin, Liaoning, Ningxia, Shaanxi, Shandong, Shanghai, Tianjin, and Yunnan. These provinces began to attach importance to the protection of the ecological environment as the economy grew to a certain stage, so energy consumption was reduced to a certain extent. We find the EEKC to hold in twice as many countries as Zhang et al. (2018) due to the nonparametric CVLL regression estimator's capability to model complex nonlinearities and our dataset comprising more recent data and a longer time period. Other studies such as Li et al. (2011), Zhang and Xu (2012), and Dong et al. (2019) did not perform any test for the EEKC.

Figure-1: Plots of Estimated Cross Validated Local Linear Regressions

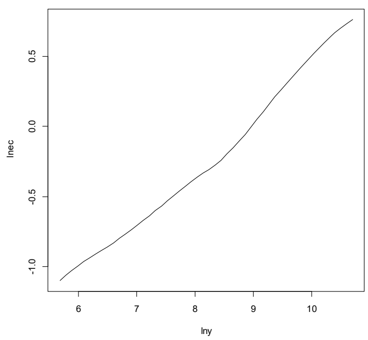
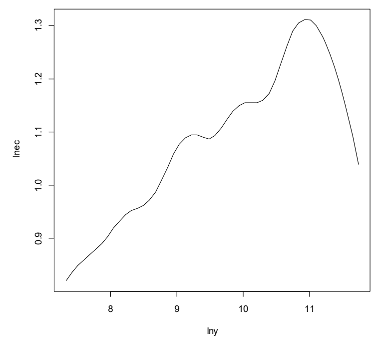
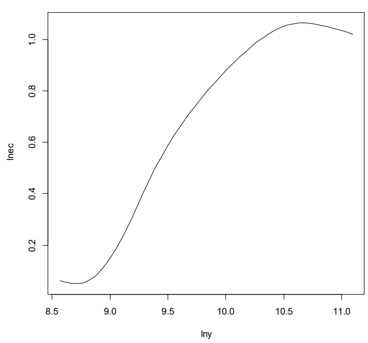
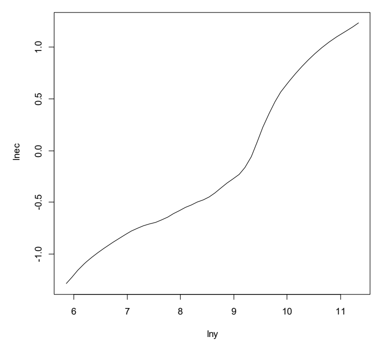
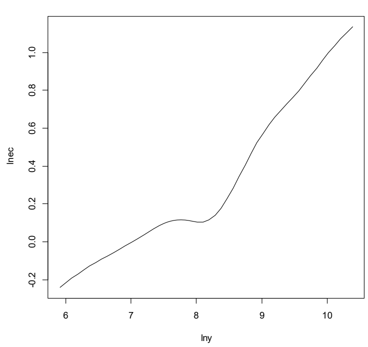
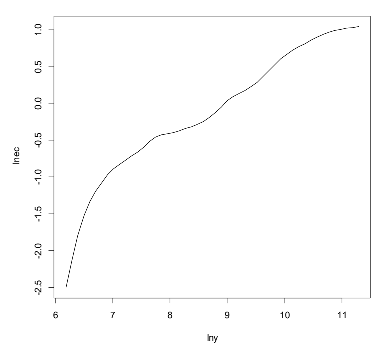
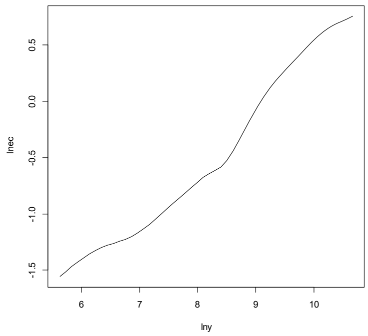
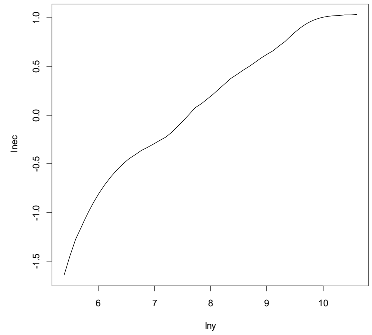
Anhui	R^2	BW	Beijing	R^2	BW
	0.999	0.248		0.992	0.148
Chongqing	R^2	BW	Fujian	R^2	BW
	0.951	0.264		0.999	0.196
Gansu	R^2	BW	Guangdong	R^2	BW
	0.998	0.198		0.999	0.156
Guangxi	R^2	BW	Guizhou	R^2	BW

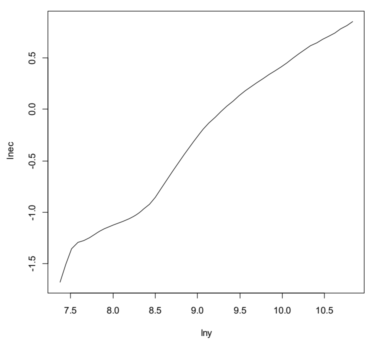
Figure-1: Plots of Estimated Cross Validated Local Linear Regressions



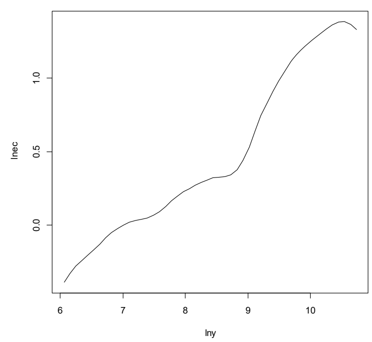
Hainan	R^2	BW
	0.999	0.193



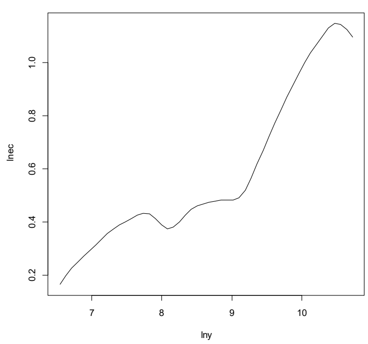
Hebei	R^2	BW
	0.998	0.207



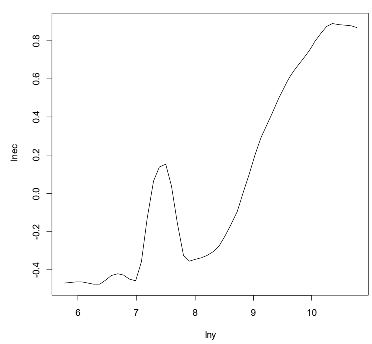
Heilongjiang	R^2	BW
	0.999	0.136



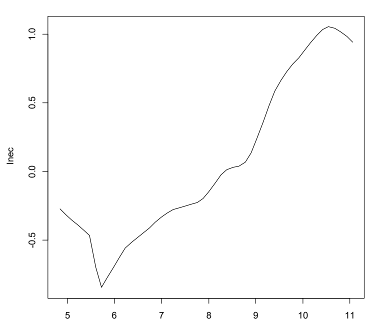
Henan	R^2	BW
	0.998	0.167



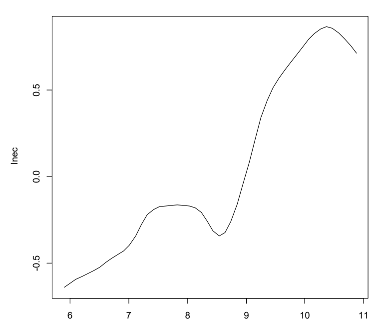
Hubei	R^2	BW
	0.996	0.148



Hunan	R^2	BW
	0.997	0.122



0.998 0.172



0.992 0.184

Figure-1: Plots of Estimated Cross Validated Local Linear Regressions

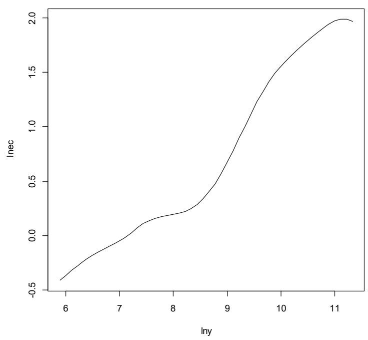
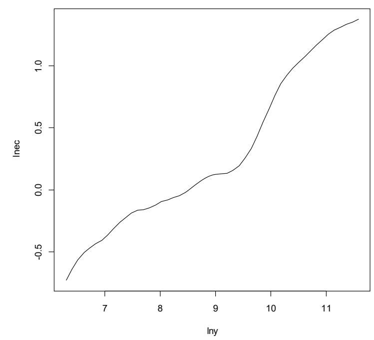
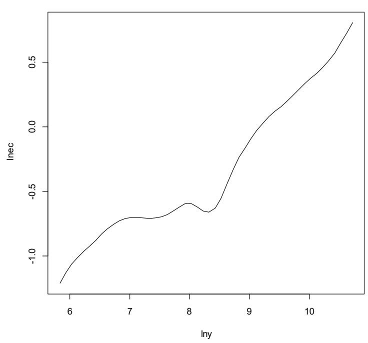
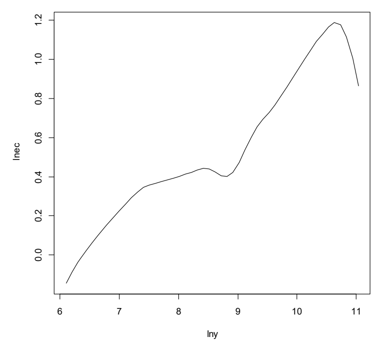
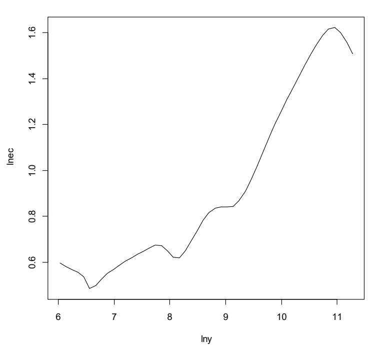
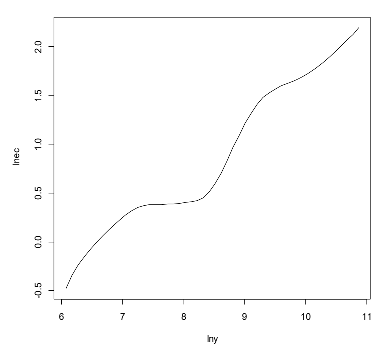
Inner Mongolia	R^2	BW	Jiangsu	R^2	BW
	0.997	0.265		1.000	0.144
Jiangxi	**R^2**	**BW**	**Jilin**	**R^2**	**BW**
	0.998	0.153		0.982	0.201
Liaoning	**R^2**	**BW**	**Ningxia**	**R^2**	**BW**
	0.996	0.168		0.997	0.209
Qinghai	**R^2**	**BW**	**Shaanxi**	**R^2**	**BW**

Figure-1: Plots of Estimated Cross Validated Local Linear Regressions

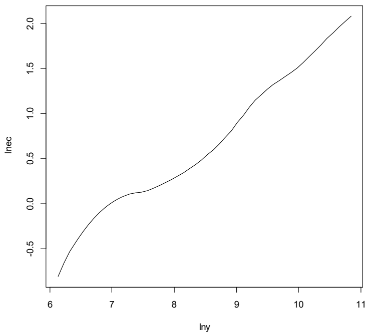
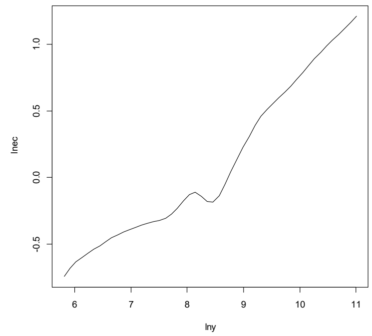
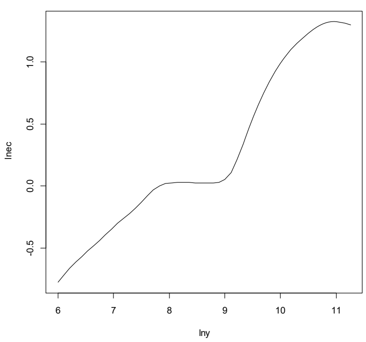
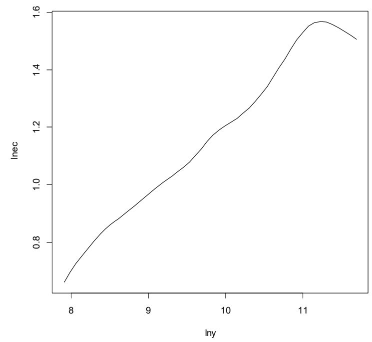
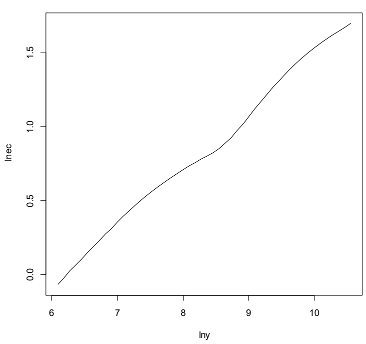
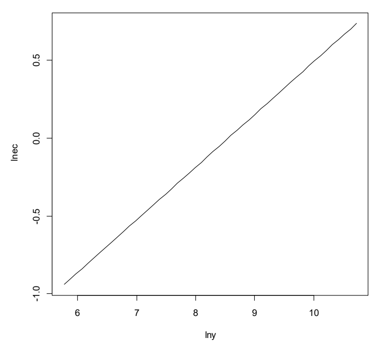
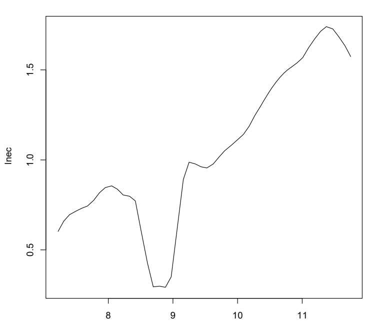
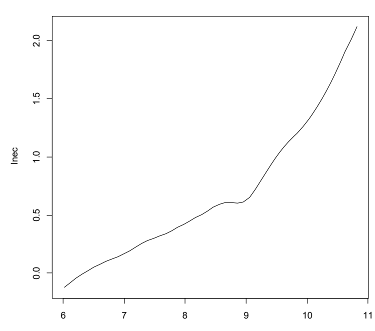
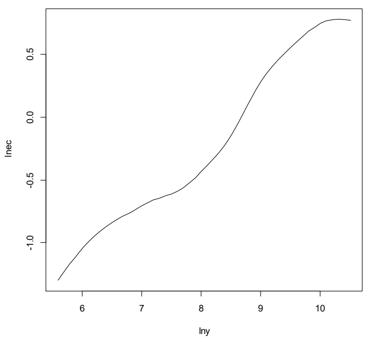
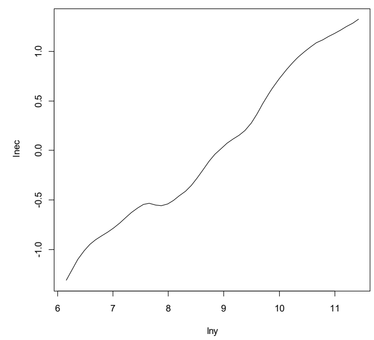
	0.996	0.241		0.997	0.168
Shandong	R^2	BW	Shanghai	R^2	BW
	0.994	0.229		0.997	0.170
Shanxi	R^2	BW	Sichuan	R^2	BW
	0.970	0.431		0.689	16.157
Tianjin	R^2	BW	Xinjiang	R^2	BW
	0.998	0.098		0.994	0.212

Figure-1: Plots of Estimated Cross Validated Local Linear Regressions

Yunnan	R^2	BW	Zhejiang	R^2	BW
	0.998	0.231		0.999	0.164

Notes: Bandwidth is abbreviated as BW and is fixed type. The continuous Kernel is second-order Gaussian.

Table-8 Tables-8 and 9 provide the estimated Hiemstra-Jones (1994) and Diks-Panchenko (2006) test statistics as well as the respective p-values and bandwidths for each direction between $\ln EC_t$ and $\ln Y_t$ in each of 30 provinces. The null hypothesis of non-causation is rejected for the direction $\ln Y_t \Rightarrow \ln EC_t$ in eight provinces: Anhui, Fujian, Gansu, Shanghai, Sichuan, Xinjiang, Yunnan, and Zhejiang. This indicates that unidirectional Granger causality runs from economic growth to energy consumption in these provinces. Energy consumption will increase with the growth of economic aggregate, and the increase in energy consumption will not bring economic growth. Reflecting that these provinces are currently focusing more on single economic growth, they have not paid attention to improving energy efficiency and protecting the ecological environment. In the direction $\ln EC_t \Rightarrow \ln Y_t$, the null hypothesis is rejected for an additional eight provinces: Beijing, Chongqing, Guangxi, Hainan, Hunan, Jiangsu, and Tianjin. This shows the presence of unidirectional causation from energy consumption to economic growth in these eight provinces. Economic growth will increase with the growth of energy consumption, and energy consumption will not increase with economic growth, reflecting that the energy quality of these provinces (such as energy structure, new energy varieties, etc.) has been greatly improved.

The null hypothesis is rejected for both the directions between $\ln EC_t$ and $\ln Y_t$ in 14 provinces, which include Guangdong, Guizhou, Hebei, Heilongjiang, Henan, Inner Mongolia, Jiangxi, Jilin, Liaoning, Ningxia, Qinghai, Shaanxi, Shandong, and Shanxi. Accordingly, bidirectional causality exists between energy consumption and economic growth in these 14 Chinese provinces. For these provinces, energy as a factor input, an increase in energy consumption will lead to an increase in economic output, at the same time, when economic aggregate expands, the demand for energy elements will also increase. The Granger causality findings are robust as the estimated results from

Hiemstra-Jones (1994), and Diks-Panchenko (2006) tests are identical. The bandwidths used in applying both the testing procedures are identical for most provinces and are inside the bandwidth bounds advised by Diks-Panchenko (2006). This study's findings relating to the direction of nonlinear causality in each Chinese province are novel and unique as past studies– Li et al. (2011), Zhang et al. (2018), and Dong et al. (2019)–do not perform the Granger causality tests by province. Zhang and Xu (2012) segregate Chinese province into three regions–Eastern, Central, and Western– and test for the direction of linear causality between energy consumption and economic growth. They find causality to be bidirectional in the Eastern region, unidirectional from economic growth to energy consumption in the Central and Western regions. While not directly comparable, a quick look indicates that our results are in some agreement with that of Zhang and Xu (2012). Any difference between our results and that of Zhang and Xu (2012) can be accounted for by the Hiemstra-Jones (1994) and Diks-Panchenko (2006) tests' ability to detect the direction of nonlinear Granger causality as well as the more recent and longer dataset that we use.

Table-8: Hiemstra-Jones (1994) Test for Direction of Granger Causality

Province	Direction	Test Statistic (T)	p-value	Bandwidth (ϵ_n)
Anhui	$\ln Y_t \Rightarrow \ln EC_t$	1.658789**	0.048579	1.300000
	$\ln EC_t \nRightarrow \ln Y_t$	0.526665	0.299213	1.300000
Beijing	$\ln Y_t \nRightarrow \ln EC_t$	0.881971	0.188896	0.550000
	$\ln EC_t \Rightarrow \ln Y_t$	1.676178**	0.046852	0.550000
Chongqing	$\ln Y_t \nRightarrow \ln EC_t$	0.553434	0.289983	1.400000
	$\ln EC_t \Rightarrow \ln Y_t$	1.332661*	0.091322	1.400000
Fujian	$\ln Y_t \Rightarrow \ln EC_t$	1.450081*	0.073518	1.500000
	$\ln EC_t \nRightarrow \ln Y_t$	0.486813	0.313195	1.500000
Gansu	$\ln Y_t \Rightarrow \ln EC_t$	1.423129*	0.077349	0.500000
	$\ln EC_t \nRightarrow \ln Y_t$	0.686154	0.246308	0.500000
Guangdong	$\ln Y_t \Rightarrow \ln EC_t$	1.512619*	0.065188	0.900000
	$\ln EC_t \Rightarrow \ln Y_t$	1.637554*	0.050757	0.700000
Guangxi	$\ln Y_t \nRightarrow \ln EC_t$	1.158728	0.123284	0.500000
	$\ln EC_t \Rightarrow \ln Y_t$	1.451524*	0.073317	0.500000
Guizhou	$\ln Y_t \Rightarrow \ln EC_t$	2.117812**	0.017096	0.600000
	$\ln EC_t \Rightarrow \ln Y_t$	1.346276*	0.089107	0.800000
Hainan	$\ln Y_t \nRightarrow \ln EC_t$	-1.134215	0.871648	1.200000
	$\ln EC_t \Rightarrow \ln Y_t$	1.342383*	0.089736	1.500000
Hebei	$\ln Y_t \Rightarrow \ln EC_t$	1.406533*	0.079783	1.500000
	$\ln EC_t \Rightarrow \ln Y_t$	1.446372*	0.074036	0.500000
Heilongjiang	$\ln Y_t \Rightarrow \ln EC_t$	1.541535*	0.061593	1.500000
	$\ln EC_t \Rightarrow \ln Y_t$	1.645117**	0.049973	0.500000
Henan	$\ln Y_t \Rightarrow \ln EC_t$	1.596158*	0.055227	1.400000
	$\ln EC_t \Rightarrow \ln Y_t$	2.200419**	0.013889	0.900000
Hubei	$\ln Y_t \nRightarrow \ln EC_t$	0.945418	0.172223	0.730000
	$\ln EC_t \Rightarrow \ln Y_t$	1.399591*	0.080818	0.620000
Hunan	$\ln Y_t \nRightarrow \ln EC_t$	1.081539	0.139729	0.700000
	$\ln EC_t \Rightarrow \ln Y_t$	1.903676**	0.028476	0.700000
Inner Mongolia	$\ln Y_t \Rightarrow \ln EC_t$	1.907581**	0.028223	0.700000

Table-8: Hiemstra-Jones (1994) Test for Direction of Granger Causality

Province	Direction	Test Statistic (T)	p-value	Bandwidth (ϵ_n)
	$\ln EC_t \Rightarrow \ln Y_t$	1.541287*	0.061624	1.100000
Jiangsu	$\ln Y_t \nRightarrow \ln EC_t$	0.674230	0.250083	0.600000
	$\ln EC_t \Rightarrow \ln Y_t$	1.396478*	0.081285	0.600000
Jiangxi	$\ln Y_t \Rightarrow \ln EC_t$	1.725805**	0.042191	1.400000
	$\ln EC_t \Rightarrow \ln Y_t$	1.338324*	0.090395	0.800000
Jilin	$\ln Y_t \Rightarrow \ln EC_t$	1.554377*	0.060047	1.300000
	$\ln EC_t \Rightarrow \ln Y_t$	1.423958*	0.077229	0.900000
Liaoning	$\ln Y_t \Rightarrow \ln EC_t$	1.826419**	0.033894	0.500000
	$\ln EC_t \Rightarrow \ln Y_t$	1.669520**	0.047507	0.600000
Ningxia	$\ln Y_t \Rightarrow \ln EC_t$	1.308637*	0.095329	1.500000
	$\ln EC_t \Rightarrow \ln Y_t$	1.648553**	0.049620	0.900000
Qinghai	$\ln Y_t \Rightarrow \ln EC_t$	1.345606*	0.089215	1.500000
	$\ln EC_t \Rightarrow \ln Y_t$	1.711550**	0.043490	1.000000
Shaanxi	$\ln Y_t \Rightarrow \ln EC_t$	1.471392*	0.070593	1.000000
	$\ln EC_t \Rightarrow \ln Y_t$	1.552190*	0.060308	1.000000
Shandong	$\ln Y_t \Rightarrow \ln EC_t$	1.330267*	0.091715	1.400000
	$\ln EC_t \Rightarrow \ln Y_t$	1.526241*	0.063475	0.630000
Shanghai	$\ln Y_t \Rightarrow \ln EC_t$	1.351446*	0.088276	1.500000
	$\ln EC_t \nRightarrow \ln Y_t$	0.722473	0.235002	1.500000
Shanxi	$\ln Y_t \Rightarrow \ln EC_t$	1.518200*	0.064482	1.000000
	$\ln EC_t \Rightarrow \ln Y_t$	1.490614*	0.068031	1.000000
Sichuan	$\ln Y_t \Rightarrow \ln EC_t$	1.327190*	0.092223	1.400000
	$\ln EC_t \nRightarrow \ln Y_t$	-0.716477	0.763151	1.500000
Tianjin	$\ln Y_t \nRightarrow \ln EC_t$	1.132485	0.128715	0.800000
	$\ln EC_t \Rightarrow \ln Y_t$	1.543412*	0.061365	0.800000
Xinjiang	$\ln Y_t \Rightarrow \ln EC_t$	1.421949*	0.077521	1.500000
	$\ln EC_t \nRightarrow \ln Y_t$	-0.724469	0.765611	1.500000
Yunnan	$\ln Y_t \Rightarrow \ln EC_t$	1.375226*	0.084531	0.500000
	$\ln EC_t \nRightarrow \ln Y_t$	1.148586	0.125363	0.500000
Zhejiang	$\ln Y_t \Rightarrow \ln EC_t$	1.542707*	0.061451	1.000000
	$\ln EC_t \nRightarrow \ln Y_t$	-1.424674	0.922874	1.000000

Notes: H_0: No causation in the direction. ** When p-value < 0.050000, reject H_0 at 5% level. * When p-value < 0.100000, reject H_0 at 10% level.

Table-9: Diks-Panchenko (2006) Test for Direction of Granger Causality

Province	Direction	Test Statistic ($T_n(\epsilon_n)$)	p-value	Bandwidth (ϵ_n)
Anhui	$\ln Y_t \Rightarrow \ln EC_t$	1.551*	0.06047	1.300000
	$\ln EC_t \nRightarrow \ln Y_t$	0.652	0.25731	1.300000
Beijing	$\ln Y_t \nRightarrow \ln EC_t$	0.796	0.21315	0.550000
	$\ln EC_t \Rightarrow \ln Y_t$	1.538*	0.06199	0.550000
Chongqing	$\ln Y_t \nRightarrow \ln EC_t$	0.682	0.24754	1.400000
	$\ln EC_t \Rightarrow \ln Y_t$	1.310*	0.09503	1.400000
Fujian	$\ln Y_t \Rightarrow \ln EC_t$	1.494*	0.06759	1.500000
	$\ln EC_t \nRightarrow \ln Y_t$	0.623	0.26649	1.500000
Gansu	$\ln Y_t \Rightarrow \ln EC_t$	1.359*	0.08713	0.500000
	$\ln EC_t \nRightarrow \ln Y_t$	0.863	0.19401	0.500000
Guangdong	$\ln Y_t \Rightarrow \ln EC_t$	1.369*	0.08554	0.900000
	$\ln EC_t \Rightarrow \ln Y_t$	1.441*	0.07478	0.700000
Guangxi	$\ln Y_t \nRightarrow \ln EC_t$	0.982	0.16317	0.800000
	$\ln EC_t \Rightarrow \ln Y_t$	1.431*	0.07614	0.800000

Table-8: Hiemstra-Jones (1994) Test for Direction of Granger Causality

Province	Direction	Test Statistic (T)	p-value	Bandwidth (ϵ_n)
Guizhou	$\ln Y_t \Rightarrow \ln EC_t$	1.661**	0.04832	0.600000
	$\ln EC_t \Rightarrow \ln Y_t$	1.434*	0.07581	0.800000
Hainan	$\ln Y_t \nRightarrow \ln EC_t$	-0.992	0.83950	1.200000
	$\ln EC_t \Rightarrow \ln Y_t$	1.340*	0.09008	1.500000
Hebei	$\ln Y_t \Rightarrow \ln EC_t$	1.415*	0.07857	1.500000
	$\ln EC_t \Rightarrow \ln Y_t$	1.385*	0.08296	0.500000
Heilongjiang	$\ln Y_t \Rightarrow \ln EC_t$	1.584*	0.05664	1.500000
	$\ln EC_t \Rightarrow \ln Y_t$	1.572*	0.05801	0.500000
Henan	$\ln Y_t \Rightarrow \ln EC_t$	1.610*	0.05372	1.400000
	$\ln EC_t \Rightarrow \ln Y_t$	2.146**	0.01595	0.900000
Hubei	$\ln Y_t \nRightarrow \ln EC_t$	1.031	0.15118	0.730000
	$\ln EC_t \Rightarrow \ln Y_t$	1.354*	0.08784	0.730000
Hunan	$\ln Y_t \nRightarrow \ln EC_t$	0.695	0.24361	0.700000
	$\ln EC_t \Rightarrow \ln Y_t$	1.924**	0.02719	0.700000
Inner Mongolia	$\ln Y_t \Rightarrow \ln EC_t$	1.424*	0.07728	0.700000
	$\ln EC_t \Rightarrow \ln Y_t$	1.496*	0.06730	1.100000
Jiangsu	$\ln Y_t \nRightarrow \ln EC_t$	0.677	0.24907	0.600000
	$\ln EC_t \Rightarrow \ln Y_t$	1.464*	0.07165	0.600000
Jiangxi	$\ln Y_t \Rightarrow \ln EC_t$	1.714**	0.04328	1.400000
	$\ln EC_t \Rightarrow \ln Y_t$	1.455*	0.07281	0.800000
Jilin	$\ln Y_t \Rightarrow \ln EC_t$	1.498*	0.06712	1.300000
	$\ln EC_t \Rightarrow \ln Y_t$	1.505*	0.06616	0.900000
Liaoning	$\ln Y_t \Rightarrow \ln EC_t$	1.297*	0.09737	0.500000
	$\ln EC_t \Rightarrow \ln Y_t$	1.380*	0.08385	0.800000
Ningxia	$\ln Y_t \Rightarrow \ln EC_t$	1.330*	0.09169	1.500000
	$\ln EC_t \Rightarrow \ln Y_t$	1.759**	0.03928	0.800000
Qinghai	$\ln Y_t \Rightarrow \ln EC_t$	1.429*	0.07651	1.500000
	$\ln EC_t \Rightarrow \ln Y_t$	1.600*	0.05477	1.000000
Shaanxi	$\ln Y_t \Rightarrow \ln EC_t$	1.352*	0.08823	1.000000
	$\ln EC_t \Rightarrow \ln Y_t$	1.500*	0.06687	1.000000
Shandong	$\ln Y_t \Rightarrow \ln EC_t$	1.341*	0.09002	1.400000
	$\ln EC_t \Rightarrow \ln Y_t$	1.317*	0.09390	0.600000
Shanghai	$\ln Y_t \Rightarrow \ln EC_t$	1.328*	0.09206	1.500000
	$\ln EC_t \nRightarrow \ln Y_t$	0.701	0.24172	1.500000
Shanxi	$\ln Y_t \Rightarrow \ln EC_t$	1.316*	0.09413	1.000000
	$\ln EC_t \Rightarrow \ln Y_t$	1.475*	0.07012	1.000000
Sichuan	$\ln Y_t \Rightarrow \ln EC_t$	1.395*	0.08154	1.500000
	$\ln EC_t \nRightarrow \ln Y_t$	-0.703	0.75883	1.500000
Tianjin	$\ln Y_t \nRightarrow \ln EC_t$	1.042	0.14877	0.700000
	$\ln EC_t \Rightarrow \ln Y_t$	1.772**	0.03822	0.700000
Xinjiang	$\ln Y_t \Rightarrow \ln EC_t$	1.474*	0.07018	1.500000
	$\ln EC_t \nRightarrow \ln Y_t$	-0.622	0.73309	1.500000
Yunnan	$\ln Y_t \Rightarrow \ln EC_t$	1.405*	0.07998	0.500000
	$\ln EC_t \nRightarrow \ln Y_t$	0.997	0.15946	0.500000
Zhejiang	$\ln Y_t \Rightarrow \ln EC_t$	1.338*	0.09039	1.000000
	$\ln EC_t \nRightarrow \ln Y_t$	-0.972	0.83445	1.000000

Notes: H_0: No causation in the direction. ** When p-value < 0.05000, reject H_0 at 5% level. * When p-value < 0.10000, reject H_0 at 10% level.

VI. Conclusion and Policy Implications

This paper is the first attempt at implementing appropriate and novel nonparametric econometric methods to analyze the energy-growth nexus at the provincial level in China. We implement an exhaustive array of nonparametric analysis, including tests for nonlinearity, structural change, unit root, cointegration, the direction of Granger causality, and long-run correlation on a dataset covering 30 Chinese provinces from 1980 to 2018. The empirical estimates find evidence of nonlinearity and structural change (smooth and/or abrupt) in most of the Chinese provinces. Tests also establish nonlinear unit roots in energy consumption and economic growth data as well as nonlinear cointegration between these two variables in each province. The nonparametric panel cointegration tests reveal convergence in energy usage and growth patterns among most of the Chinese provinces.

The nonparametric local linear regression analysis reveals a positive effect of economic growth on energy consumption, on average, is positive in all provinces, apart from Beijing, where the effect is found to be negative. The nonparametric CVLL regression plots present a multitude of shapes of the energy-growth nexus amongst the provinces, including the more traditional shapes such as linear, U- and inverted U-shaped, as well as more intricates shapes resembling S, M, W, and multiple inverted U's. In addition, the CVLL plots indicate that the EEKC is present in Beijing, Chongqing, Guangdong, Guizhou, Hebei, Heilongjiang, Henan, Hubei, Hunan, Inner Mongolia, Jiangsu, Jiangxi, Jilin, Liaoning, Ningxia, Shaanxi, Shandong, Shanghai, Tianjin, and Yunnan (20 of the 30 provinces). The Granger causality tests find unidirectional causality from economic growth to energy consumption in eight provinces, unidirectional causality from energy consumption to economic growth in further eight provinces, and bidirectional causality between economic growth and energy consumption in remaining 14 provinces. The robustness of these estimated results is given by performing each type of testing–unit root, cointegration, Granger causality, and regression analysis–using two techniques, the results from which are identical in all cases.

Based on the above empirical conclusions, we offer the following policy recommendations. China is a country with a per capita energy shortage. Energy supply is an important bottleneck that affects China's economic growth. Energy consumption is a rigid factor in economic growth. With the acceleration of urbanization and the upgrading of consumption structure in China, it is obviously unrealistic to expect a "cliff-like" decline in energy consumption in the short term, and the task of energy conservation and emission reduction in the future is still severe. In view of the characteristics of EEKC in most of China's provinces, the current priority is to optimize the industrial structure, prioritize the development of modern service industries, continuously increase the proportion of the tertiary industry, promote optimization and upgrading of secondary industry, and gradually adopt high-tech industries with low energy consumption. Replace metallurgical, building materials, and chemical industries with high energy consumption. At the same time, China should accelerate the optimization of its energy structure, vigorously develop and increase the proportion of clean energy and alternative energy in primary energy consumption. Through the guidance of economic structural adjustment of the transformation and upgrading of traditional industries, encourage the development and adoption of new energy sources, such as nuclear power, wind power and solar energy use multiple paths to dig the potential of energy conservation and emissions reduction, on the supply side to drive the development strategy of structural reform and innovation, relying on technological progress and economic structure adjustment to realize green growth. Thereby accelerating the process to the right of the EEKC inflection point is achieving economic growth while reducing energy consumption.

Regarding the different results of Granger causality in different provinces, different provinces should make good use of this research conclusion according to local conditions, so as to delay or slow down the restrictive effect of energy supply on economic growth. The Chinese government should encourage the introduction of foreign advanced technology and independent innovation, and realize the non-linear impact of economic growth on energy consumption via technological progress. At the same time, the local government's performance appraisal system that simply inspects GDP will be changed, and indicators such as major pollutant emissions, total energy consumption, and energy utilization efficiency will be included in the appraisal system. To reduce energy intensity and pollution emissions as the goal of environmental policy, including efforts to improve the efficiency and demand side of the control policy, in a short period of time is bound to be some negative impact on China's economic activity, but in the long run, the negative effect will be weakened, and the energy conservation and emissions reduction policy can be implemented for a long time, so as to ultimately achieve coordinated development of energy conservation and economic growth.

Though this study has covered the panel data of 30 provinces in China from 1980 to 2018, the analysis is not comprehensive owing to data limitations given the microdata at the prefecture-level as well as the city level. In the future, it is necessary to study the energy consumption–economic growth nexus at the micro level to find more phenomena worth discussing from the micro perspective.

Appendix A. Supplementary data

Supplementary data to this article can be found online.

References

Acaravci, A. and Ozturk, I. (2010). Electricity consumption-growth nexus: Evidence from panel data for transition countries. *Energy Economics, 32*(3), 604-608. doi:10.1016/j.eneco.2009.10.016

Agras, J. and Chapman, D. (1999). A dynamic approach to the Environmental Kuznets Curve hypothesis. *Ecological economics, 28*(2), 267-277.

Ajmi, A. N., Hammoudeh, S., Nguyen, D. K. and Sato, J. R. (2013). On the relationships between CO2 emissions, energy consumption and income: The importance of time variation. *Energy Economics, 49*, 629-638.

Al-Mulali, U., Saboori, B. and Ozturk, I. (2015). Investigating the environmental Kuznets curve hypothesis in Vietnam. *Energy Policy, 76*, 123-131.

Andersson, F. N. and Karpestam, P. (2013). CO2 emissions and economic activity: Short-and long-run economic determinants of scale, energy intensity and carbon intensity. *Energy Policy, 61*, 1285-1294.

Andersson, F. N. G., Edgerton, D. L. and Opper, S. (2013). A Matter of Time: Revisiting Growth Convergence in China. *World Development, 45*, 239-251.

Andersson, F. N. G., Opper, S. and Khalid, U. (2018). Are capitalists green? Firm ownership and provincial CO2 emissions in China. *Energy Policy, 123*, 349-359.

Apergis, N. and Payne, J. E. (2009). Energy consumption and economic growth: Evidence from the Commonwealth of Independent States. *Energy Economics, 31*(5), 641-647.

Apergis, N. and Payne, J. E. (2010). Energy consumption and growth in South America: Evidence from a panel error correction model. *Energy Economics, 32*(6), 1421-1426.

Azomahu, T. and Van Phu, N. (2001). Economic growth and CO2 emissions: A nonparametric approach. *BETA Working Paper N.2001-01*.

Balcilar, M., Ozdemir, Z. A. and Arslanturk, Y. (2010). Economic growth and energy consumption causal nexus viewed through a bootstrap rolling window. *Energy Economics, 32*(6), 1398-1410.

Belke, A. and Potrafke, N. (2012). Does government ideology matter in monetary policy? A panel data analysis for OECD countries. *Journal of International Money and Finance, 31*(5), 1126-1139.

Bierens, H. J. (1997a). Testing the unit root with drift hypothesis against nonlinear trend stationarity, with an application to the US price level and interest rate. *Journal of Econometrics, 81*(1), 29-64.

Bierens, H. J. (1997b). Nonparametric cointegration analysis. *Journal of Econometrics, 77*(2), 379-404.

Bloch, H., Rafiq, S. and Salim, R. (2012). Coal consumption, CO2 emission and economic growth in China: Empirical evidence and policy responses. *Energy Economics, 34*(2), 518-528.

Boden, T.A., Marland, G. and Andres, R.J. (2011). *Global, Regional, and National Fossil-Fuel CO_2 Emissions, 1751-2008 (Version 2011)*. Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge National Laboratory (ORNL), Oak Ridge, TN (United States). doi: 10.3334/CDIAC/00001_V2011

Brajer, V., Mead, R. W. and Xiao, F. (2011). Searching for an Environmental Kuznets Curve in China's air pollution. *China Economic Review, 22*(3), 383-397.

Breitung, J. (2002). Nonparametric tests for unit roots and cointegration. *Journal of Econometrics, 108*(2), 343-364.

Chandran Govindaraju, V. G. R. and Tang, C. F. (2013). The dynamic links between CO2 emissions, economic growth and coal consumption in China and India. *Applied Energy, 104*, 310-318.

Changhong, C., Bingyan, W., Qingyan, F., Green, C. and Streets, D. G. (2006). Reductions in emissions of local air pollutants and co-benefits of Chinese energy policy: a Shanghai case study. *Energy Policy, 34*(6), 754-762.

Chen, B. and Hong, Y. (2012). Testing for smooth structural changes in time series models via nonparametric regression. *Econometrica, 80*(3), 1157-1183.
Coondoo, D. and Dinda, S. (2008). Carbon dioxide emission and income: A temporal analysis of cross-country distributional patterns. *Ecological Economics, 65*(2), 375-385.
Dijkgraaf, E. and Vollebergh, H. R. J. (2005). A test for parameter homogeneity in CO2 panel EEKC estimations. *Environmental and Resource Economics, 32*(2), 229-239.
Diks, C. and Panchenko, V. (2005). A note on the Hiemstra-Jones test for Granger non-causality. *Studies in Nonlinear Dynamics & Econometrics, 9*(2), 4-10.
Diks, C. and Panchenko, V. (2006). A new statistic and practical guidelines for nonparametric Granger causality testing. *Journal of Economic Dynamics and Control, 30*(9), 1647-1669.
Dong, X.-Y., Ran, Q. and Hao, Y. (2019). On the nonlinear relationship between energy consumption and economic development in China: new evidence from panel data threshold estimations. *Quality & Quantity, 53*(4), 1837-1857.
Du, L., Wei, C. and Cai, S. (2012). Economic development and carbon dioxide emissions in China: Provincial panel data analysis. *China Economic Review, 23*(2), 371-384.
Du, T., Mao, F. and Luo, R. (2007). Study on China's economic growth and CO2 emissions. *China Population Resources and Environment, 17*(2), 94-99.
Fallahi, F. (2011). Causal relationship between energy consumption (EC) and GDP: A Markov-switching (MS) causality. *Energy, 36*(7), 4165-4170.
Fei, L., Dong, S., Xue, L., Liang, Q. and Yang, W. (2011). Energy consumption-economic growth relationship and carbon dioxide emissions in China. *Energy Policy, 39*(2), 568-574.
Ge, F., Ye, B., Xing, S., Wang, B. and Sun, S. (2017). The analysis of the underlying reasons of the inconsistent relationship between economic growth and the consumption of electricity in China–A case study of Anhui province. *Energy, 128*, 601-608.
Haisheng, Y., Jia, J., Yongzhang, Z. and Shugong, W. (2005). The Impact on Environmental Kuznets Curve by Trade and Foreign Direct Investment in China. *Chinese Journal of Population Resources and Environment, 3*(2), 14-19.
Hao, Y., Liu, Y., Weng, J.-H. and Gao, Y. (2016). Does the Environmental Kuznets Curve for coal consumption in China exist? New evidence from spatial econometric analysis. *Energy, 114*, 1214-1223.
Hao, Y., Wang, L., Fan, W., Wei, Y., Wen, T. and Zhang, K. (2018). What determines China's electricity consumption? New evidence using the logarithmic mean Divisia index method. *Journal of Renewable and Sustainable Energy, 10*(1), 015909.
Hao, Y., Zhu, L. and Ye, M. (2018). The dynamic relationship between energy consumption, investment and economic growth in China's rural area: New evidence based on provincial panel data. *Energy, 154*, 374-382.
Hiemstra, C. and Jones, J.D. (1994). Testing for linear and nonlinear Granger causality in stock-price volume relation. *Journal of Finance, 49*(5), 1639-1664.
Hsiao, C., Li, Q. and Racine, J.S. (2007). A consistent model specification test with mixed discrete and continuous data. *Journal of Econometrics, 140*(2), 802-826.
Huang, B. N., Hwang, M. J. and Yang, C. W. (2008). Causal relationship between energy consumption and GDP growth revisited: A dynamic panel data approach. *Ecological economics, 67*(1), 41-54.
Jalil, A. and Feridun, M. (2011). The impact of growth, energy and financial development on the environment in China: A cointegration analysis. *Energy Economics, 33*(2), 284-291.
Jalil, A. and Feridun, M. (2014). Energy-driven economic growth: Energy consumption—economic growth nexus revisited for China. *Emerging Markets Finance and Trade, 50*(5), 159-168.
Jalil, A. and Mahmud, S. F. (2009). Environment Kuznets curve for CO_2 emissions: A cointegration analysis for China. *Energy Policy, 37*(12), 5167-5172. doi:10.1016/j.enpol.2009.07.044

Kaika, D. and Zervas, E. (2013). The Environmental Kuznets Curve (EEKC) theory-Part A: Concept, causes and the CO2 emissions case. *Energy Policy, 62*, 1392-1402.
Kraft, J. and Kraft, A. (1978). On the relationship between energy and GNP. *The Journal of Energy and Development*, 401-403.
Lee, C. C. (2005). Energy consumption and GDP in developing countries: A cointegrated panel analysis. *Energy Economics, 27*(3), 415-427.
Lee, C. C. (2006). The causality relationship between energy consumption and GDP in G-11 countries revisited. *Energy Policy, 34*(9), 1086-1093.
Lee, C. C. and Chang, C. P. (2007). Energy consumption and GDP revisited: A panel analysis of developed and developing countries. *Energy Economics, 29*(6), 1206-1223.
Lee, C. C. and Chang, C. P. (2008). Energy consumption and economic growth in Asian economies: A more comprehensive analysis using panel data. *Resource and Energy Economics, 30*(1), 50-65.
Li, F., Dong, S., Li, X., Liang, Q. and Yang, W. (2011). Energy consumption-economic growth relationship and carbon dioxide emissions in China. *Energy policy, 39*(2), 568-574.
Li, Q. and Racine, J.S. (2004). Cross-validated local linear nonparametric regression. *Statistica Sinica, 14*(2), 485-512.
Li, Q. and Racine, J.S. (2007). *Nonparametric Econometrics: Theory and Practice*. Princeton University Press.
Lin, B. Q. and Jiang, Z. J. (2009). A forecast of the environmental Kuznets curve of carbon dioxide in China and analysis of its influencing factors. *Management World, 4*(4), 27-36.
Lise, W. nd Van Montfort, K. (2007). Energy consumption and GDP in Turkey: Is there a co-integration relationship? *Energy Economics, 29*(6), 1166-1178.
Liu, J., Cheng, Z. and Zhang, H. (2017). Does industrial agglomeration promote the increase of energy efficiency in China? *Journal of Cleaner Production, 164*, 30-37.
Liu, L. J., Song, M., Yokogawa, H. and Qu, B. X. (2008). Exploring the environmental Kuznets curve hypothesis between economic growth and farmland conversion in China. *Journal of the Faculty of Agriculture, Kyushu University, 53*(1), 321-327.
Llorca, M. and Meunié, A. (2009). SO2 emissions and the environmental Kuznets curve: the case of Chinese provinces. *Journal of Chinese Economic and Business Studies, 7*(1), 1-16.
Luzzati, T. and Orsini, M. (2009). Investigating the energy-environmental Kuznets curve. *Energy, 34*(3), 291-300.
Mahadevan, R. and Asafu-Adjaye, J. (2007). Energy consumption, economic growth and prices: A reassessment using panel VECM for developed and developing countries. *Energy Policy, 35*(4), 2481-2490.
Mehrara, M. (2007). Testing the Purchasing Power Parity in Oil-Exporting Countries. *OPEC Review, 31*, 249-260.
Narayan, P. K. and Smyth, R. (2008). Energy consumption and real GDP in G7 countries: New evidence from panel cointegration with structural breaks. *Energy Economics, 30*(5), 2331-2341.
Nasir, M. and Ur Rehman, F. (2011). Environmental Kuznets Curve for carbon emissions in Pakistan: An empirical investigation. *Energy Policy, 39*(3), 1857-1864.
Oh, W. and Lee, K. (2004). Causal relationship between energy consumption and GDP revisited: The case of Korea 1970-1999. *Energy Economics, 26*(1), 51-59.
Olale, E., Ochuodho, T. O., Lantz, V. and El Armali, J. (2018). The environmental Kuznets curve model for greenhouse gas emissions in Canada. *Journal of Cleaner Production, 184*, 859-868.
Onafowora, O. A. and Owoye, O. (2014). Bounds testing approach to analysis of the environment Kuznets curve hypothesis. *Energy Economics, 44*, 47-62.
Ozturk, I. (2010). A literature survey on energy–growth nexus. *Energy Policy, 38*(1), 340-349.

Ozturk, I., Aslan, A. and Kalyoncu, H. (2010). Energy consumption and economic growth relationship: Evidence from panel data for low and middle income countries. *Energy Policy, 38*(8), 4422-4428.

Pablo-Romero, M. d. P. and De Jesús, J. (2016). Economic growth and energy consumption: The Energy-Environmental Kuznets Curve for Latin America and the Caribbean. *Renewable and Sustainable Energy Reviews, 60*, 1343-1350.

Pao, H.T. and Tsai, C.M. (2010). CO_2 emissions, energy consumption and economic growth in BRIC countries. *Energy Policy, 38*(12), 7850-7860.

Pedroni, P.L., Vogelsang, T.J., Wagner, M. and Westerlund, J. (2015). Nonparametric rank tests for nonstationary panels. *Journal of Econometrics, 185*(2), 378-391.

Rahman, Z., Khattak, S. I., Ahmad, M. and Khan, A. (2020). A disaggregated-level analysis of the relationship among energy production, energy consumption and economic growth: Evidence from China. *Energy, 194*, 116836.

Richmond, A. K. and Kaufmann, R. K. (2006). Energy prices and turning points: the relationship between income and energy use/carbon emissions. *The Energy Journal, 27*(4).

Riti, J. S., Song, D., Shu, Y. and Kamah, M. (2017). Decoupling CO2 emission and economic growth in China: Is there consistency in estimation results in analyzing environmental Kuznets curve? *Journal of Cleaner Production, 166*, 1448-1461.

Roumasset, J., Burnett, K. and Wang, H. (2008). Environmental Resources and Economic Growth. In L. Brandt & T. G. Rawski (Eds.), *China's Great Economic Transformation* (pp. 250-285). Cambridge: Cambridge University Press.

Saboori, B. and Sulaiman, J. (2013). Environmental degradation, economic growth and energy consumption: Evidence of the environmental Kuznets curve in Malaysia. *Energy Policy, 60*, 892-905.

Shahbaz, M., Khan, S. and Tahir, M. I. (2013). The dynamic links between energy consumption, economic growth, financial development and trade in China: Fresh evidence from multivariate framework analysis. *Energy Economics, 40*, 8-21.

Shahbaz, M., Mallick, H., Mahalik, M.K. and Sadorsky, P. (2016). The role of globalization on the recent evolution of energy demand in India: Implications for sustainable development. *Energy Economics, 55*, 52-68.

Shahbaz, M., Shafiullah, M., and Mahalik, M. K. (2019). The dynamics of financial development, globalisation, economic growth and life expectancy in sub-Saharan Africa. *Australian Economic Papers, 58*(4), 444-479.

Shahbaz, M., Shafiullah, M., Papavassiliou, V.G. and Hammoudeh, S. (2017a). The CO_2–growth nexus revisited: A nonparametric analysis for the G7 economies over nearly two centuries. *Energy Economics, 65*, 183-193.

Shahbaz, M., Van Hoang, T.H., Mahalik, M.K. and Roubaud, D. (2017b). Energy consumption, financial development and economic growth in India: New evidence from a nonlinear and asymmetric analysis. *Energy Economics, 63*, 199-212.

Song, M.-L., Zhang, W. and Wang, S.-H. (2013). Inflection point of environmental Kuznets curve in Mainland China. *Energy Policy, 57*, 14-20.

Song, T., Zheng, T. and Lianjun, T. (2008). An empirical test of the environmental Kuznets curve in China: a panel cointegration approach. *China Economic Review, 19*(3), 381-392.

Soytas, U. and Sari, R. (2003). Energy consumption and GDP: causality relationship in G-7 countries and emerging markets. *Energy economics, 25*(1), 33-37.

Steger, S. and Bleischwitz, R. (2017). Decoupling GDP from resource use, resource productivity and competitiveness: A cross-country comparison 1. In *Sustainable growth and resource productivity* (pp. 172-193). Routledge.

Suri, V. and Chapman, D. (1998). Economic growth, trade and energy: implications for the environmental Kuznets curve. *Ecological economics, 25*(2), 195-208.

Tiba, S. and Omri, A. (2017). Literature survey on the relationships between energy, environment and economic growth. *Renewable and Sustainable Energy Reviews, 69*, 1129-1146. doi:https://doi.org/10.1016/j.rser.2016.09.113

Ulucak, R. and Bilgili, F. (2018). A reinvestigation of EEKC model by ecological footprint measurement for high, middle and low income countries. *Journal of Cleaner Production, 188*, 144-157.

Voigt, S., De Cian, E., Schymura, M. and Verdolini, E. (2014). Energy intensity developments in 40 major economies: structural change or technology improvement? *Energy Economics, 41*, 47-62.

Wagner, M. (2015). The Environmental Kuznets Curve, Cointegration and Nonlinearity. *Journal of Applied Econometrics, 30*(6), 948-967.

Wang, R., Liu, W., Xiao, L., Liu, J. and Kao, W. (2011). Path towards achieving of China's 2020 carbon emission reduction target—A discussion of low-carbon energy policies at province level. *Energy Policy, 39*(5), 2740-2747.

Wang, H., Jiang, Z. G. and Wang, Y. (2018). A two-stage optimization method for energy-saving flexible job-shop scheduling based on energy dynamic characterization. Journal of Cleaner Production, 188, 575-588.

Wang, X., Wei, Y. and Shao, Q. (2020). Decomposing the decoupling of CO2 emissions and economic growth in China's iron and steel industry. *Resources, Conservation and Recycling, 152*, 104509.

Wolde-Rufael, Y. (2009). Energy consumption and economic growth: The experience of African countries revisited. *Energy Economics, 31*(2), 217-224.

Wu, Q., Chen, L., Zhang, Y. and Cheng, J. (2008). Retesting the granger causality between energy consumption and GDP in China: based on the provincial panel data analysis. *The Journal of Quantitative & Technical Economics, 6*, 27-40.

Xia, Y. and Zhong, M. (2016). Relationship between EEKC hypothesis and the decoupling of environmental pollution from economic development: Based on China prefecture-level cities' decoupling partition. *China Popul. Resour. Environ, 26*, 8-16.

Xu, X., Zhao, T., Liu, N. and Kang, J. (2014). Changes of energy-related GHG emissions in China: An empirical analysis from sectoral perspective. *Applied Energy, 132*, 298-307.

Yaguchi, Y., Sonobe, T. and Otsuka, K. (2007). Beyond the environmental Kuznets curve: a comparative study of SO 2 and CO 2 emissions between Japan and China. *Environment and Development Economics, 12*(3), 445-470.

Yang, H., He, J. and Chen, S. (2015). The fragility of the Environmental Kuznets Curve: Revisiting the hypothesis with Chinese data via an "Extreme Bound Analysis". *Ecological Economics, 109*, 41-58.

Yang, T., Gbaguidi, A., Yan, P., Zhang, W., Zhu, L., Yao, X. and Chen, H. (2017). Model elucidating the sources and formation mechanisms of severe haze pollution over Northeast mega-city cluster in China. *Environmental Pollution, 230*, 692-700.

Yin, J., Zheng, M. and Chen, J. (2015). The effects of environmental regulation and technical progress on CO2 Kuznets curve: An evidence from China. *Energy Policy, 77*, 97-108.

Zhang, C. and Xu, J. (2012). Retesting the causality between energy consumption and GDP in China: Evidence from sectoral and regional analyses using dynamic panel data. *Energy Economics, 34*(6), 1782-1789.

Zhang, C., Su, B., Zhou, K. and Yang, S. (2019). Analysis of electricity consumption in China (1990–2016) using index decomposition and decoupling approach. *Journal of Cleaner Production, 209*, 224-235.

Zhang, Q., Liao, H. and Hao, Y. (2018). Does one path fit all? An empirical study on the relationship between energy consumption and economic development for individual Chinese provinces. *Energy, 150*, 527-543.

Zhang, X., Zhao, Y., Wang, C., Wang, F. and Qiu, F. (2019). Decoupling effect and sectoral attribution analysis of industrial energy-related carbon emissions in Xinjiang, China. *Ecological Indicators, 97*, 1-9.

Zhang, X.P. and Cheng, X.M. (2009). Energy consumption, carbon emissions, and economic growth in China. *Ecological Economics, 68*(10), 2706-2712.

Zheng, S., Lam, C.-M., Hsu, S.-C. and Ren, J. (2018). Evaluating efficiency of energy conservation measures in energy service companies in China. *Energy Policy, 122*, 580-591.

Ziolkowska, J.R. and Ziolkowski, B. (2011). Product generational dematerialization indicator: A case of crude oil in the global economy. *Energy, 36*(10), 5925-5934.

Appendix A. Supplementary Data

Table A1: Summary of the studies in literature review

Study	Time Period	Countries/Regions	Methodology	Results
Acaravci and Ozturk (2010)	1990-2006	15 Transition Countries (Eastern Europe)	Pedroni Panel Cointegration (PPC)	EC ⇎ GDP.
Agras and Chapman (1999)	1950-1988	34 Countries	AR Lag Model	EEKC not supported.
Ajmi et al. (2013)	1960-2010	G7 Countries	Time-Varying Granger Causality Test.	EC ⟹ GDP, GDP ⟹ EC, EC ⟹ GDP EC ⟹ CO_2 emissions, EC ⟹ CO_2 emissions, GDP ⟹ CO_2 emissions. EEKC not supported.
Al-Mulali et al. (2015)	1981-2011	Vietnam	Autoregressive Distributed Lag Model (ARDL)	EEKC not supported.
Andersson and Karpestam (2013)	1973-2007	10 Countries (8 High, 2 Emerging)	Band Spectrum Regression	Short-run: Business Cycles/External Shocks ⟹ Emissions. Long-run: Capital Growth ⟹ Emissions. Productivity Growth ⟹ Lower Emissions.
Andersson et al. (2013)	1978-2009	China	Principal Component Analysis (PCA)	S-R: Province Growth Divergence. L-R: Converging province growth groups.
Andersson et al. (2018)	1992-2010	China	Band Spectrum Regression	Public Sector Emissions > Private Sector Emissions
Apergis and Payne (2009)	1991-2005	11 Countries (Commonwealth of Independent States)	Pedroni Panel Cointegration Error Correction Model (ECM)	Short-Run: EC ⟹ GDP Long-Run: EC ⟹ GDP
Apergis and Payne (2010)	1980-2005	9 Countries (South America)	Pedroni Panel Cointegration ECM Granger Causality	Short-Run: EC ⟹ GDP Long-Run: EC ⟹ GDP
Azomahou and Van Phu (2001)	1960-1996	100 countries	Non-Parametric Specification	Constancy between GDP and CO_2 emissions. EEKC not supported.
Balcilar et al. (2010)	1960-2006	G7 Countries (excluding Germany)	Bootstrap Granger Non-Causality Test. Bootstrap Rolling Window	EC ⟹ GDP (only for some subsamples). No consistent causal links for EC and GDP.

Table A1: Summary of the studies in literature review				
Study	**Time Period**	**Countries/Regions**	**Methodology**	**Results**
Bloch et al. (2012)	1965-2008	China	Cointegration VECM	Supply Side: (Short-Run and Long-Run) Coal Consumption ⟹ GDP Demand Side: (Short-Run and Long-Run) Output ⟹ Coal Consumption Short-Run and Long-Run: Coal Consumption ⟺ Emissions
Brajer et al. (2011)	1990-2006	China	GLS Estimator (Random Effects)	EEKC supported.
Govindaraju and Tang (2013)	1965-2009	China and India	Cointegration Test (Bayer and Hanck). Granger Causality	China: GDP ⟹ CO_2 emissions. Short-Run and Long-Run: GDP⟺ Coal consumption Coal consumption ⟺ CO_2 emissions. India: (Only Short-Run causalities) GDP⟺ CO_2 emissions CO_2 emissions ⟺ Coal Consumption GDP ⟹ Coal Consumption
Changhong et al. (2006)	1995-2005	China	MARKAL Model Forecasting	Shanghai will see a continuous increase in energy consumption but with a changing energy structure.
Coondoo and Dinda (2008)	1960-1990	88 Countries	Johansen Cointegration Analysis.	Country income inequality ⟹ country mean emission. EEKC supported.
Dijkgraaf and Vollebergh	1960-1997	OECD Countries	Polynomial Reduced Form Specification (Fixed Effects).	EEKC not supported.
Dong et al. (2019	1985-2014	China	Panel Threshold Regression Model	No nonlinear relationship between EC and GDP. EEKC not supported.
Du et al. (2012)	1995-2009	China	Static and Dynamic Panel Data Models Optimal Forecasting Model	EEKC not supported.
Fallahi (2011)	1960-2005	USA	Markov-Switching VAR	1st Regime: EC ⟺ GDP 2nd Regime: No Granger Causality
Fei et al. (2011)	1985-2007	China	Panel Unit Root Panel Cointegration Panel-Based Dynamic OLS	Positive long-run cointegrated relationship between GDP per capita and Energy Consumption.

Table A1: Summary of the studies in literature review

Study	Time Period	Countries/Regions	Methodology	Results
Ge et al. (2017)	2000-2015	China	Augmented Dickey-Fuller (ADF) Engle and Granger Cointegration Test Multivariate Regression	Real GDP positive factor of energy consumption. Industrial structure major contributor to EC.
Haisheng et al. 2005	1990-2002	China	Panel Data Model (FE and RE)	FDI ⟹ Pollutant Emission. No direct impact on EEKC from trade. EEKC supported.
Hao et al. (2016)	1995-2012	China	Spatial Durbin Model	EEKC Supported (for Coal Consumption)
Hao et al. (2018)	1995-2014	China	Logarithmic Mean Divisia Index (LDMI)	GDP ⟹ Electricity Consumption. EC ⟹ Electricity Consumption. Energy Intensity ⟹ Electricity Consumption. Population Growth ⟹ Electricity Consumption.
Hao et al. (2018)	1995-2010	China	VECM Fully Modified OLS (FMOLS)	Rural GDP⇔ Rural Investment Rural EC ⟹ Rural GDP Rural EC ⟹ Rural Investment Short-Run: Rural GDP ⟹ Rural Investment Rural GDP⇔ Rural EC
Huang et al. (2008)	1972-2002	82 Countries	GMM-SYS Panel VAR	Low Income Countries: EC ⇎ GDP Middle Income Countries: GDP ⟹ EC. High Income Countries: GDP ⟹ EC (negative).
Jalil and Feridun (2011)	1953-2006	China	ARDL	Financial Development ⟹ Pollution(negative). EEKC supported
Jalil and Feridun (2014)	1952-2008	China	ARDL	EC ⟹ GDP
Jalil and Mahmud (2009)	1975-2005	China	ARDL Granger Causality	GDP ⟹ CO_2 Emissions EEKC supported.
Kraft and Kraft (1978)	1947-1974	USA	Sims Distributed Lag Estimation	GNP ⟹ Energy Consumption
Lee (2005)	1975-2001	18 Developing Countries	Panel Unit Root Panel Cointegration ECM	Long-run and Short-run: EC ⟹ GDP
Lee (2006)	1960-2001	11 Developed Countries	Granger Non-Causality Testing (Toda and Yamamoto).	EC ⇔ GDP GDP ⟹ EC EC ⇎ GDP

Table A1: Summary of the studies in literature review

Study	Time Period	Countries/Regions	Methodology	Results
Lee and Chang (2007)	1965-2002	22 Developed Countries 18 Developing Countries	Panel Data Stationarity Testing (Carrion-i-Silvestre et al.)	Developed Countries: EC per Capita ⇔ GDP per Capita Developing Countries: GDP per Capita ⟹ EC per Capita
Lee and Chang (2008)	1971-2002	16 Countries (Asia	Panel Unit Root Panel Cointegration ECM	LR: EC ⟹ GDP SR: EC ⇎ GDP
Li et al. (2011)	1985-2007	China	Panel Unit Root Panel Cointegration Panel-Based Dynamic OLS	GDP ⟹ EC (Long-Run)
Li et al. (2016)	1996-2012	China	ARDL GMM	EEKC supported.
Lise and Van Montfort (2007)	1970-2003	Turkey	Cointegration Analysis VECM	GDP ⟹ EC EEKC not supported.
Liu et al. (2017)	2004-2013	China	Spatial Autocorrelation Test	Industrial agglomeration promotes energy efficiency.
Liu et al. (2008)	1987-2005	China	Time-Series Regression (ADF) Panel Data Regression (FE)	EEKC supported.
Llorca and Meunié (2009)	1985-2003	China	Panel Data Regression (FE) EEKC Framework	EEKC supported. (N-Shaped)
Luzzati and Orsini (2009)	1971-2004	113 Countries	Pooled Country Analysis EEKC Framework Parametric/Semi-Parametric	EEKC not supported.
Mahedavan and Asafu-Adjaye (2007)	1971-2002	20 Countries (Net Energy Importers/Exporters)	Panel VECM	HDL's (LR and SR): GDP⇔ EC LDL's (SR): EC ⟹ GDP
Narayan and Smith (2008)	1972-2002	G7 Countries	Panel Unit Root Panel Cointegration Granger Causality Long-Run Structural Estimation	EC ⟹ GDP
Nasir and Ur Rehman (2011)	1972-2008	Pakistan	Johansen Cointegration Analysis	EEKC supported.
Oh and Lee (2004)	1970-1999	South Korea	VECM	LR: EC ⇔ GDP SR: EC ⟹ GDP
Olale et al. (2018)	1990-2014	Canada	Pooled Regression Fixed Effects Regression	EEKC supported.

Table A1: Summary of the studies in literature review

Study	Time Period	Countries/Regions	Methodology	Results
Onafowora and Owoye (2014)	1970-2010	8 Countries	ARDL CUMSUMQ	U-shape: Japan and South Korea N-shape: Other 6 countries EEKC supported.
Ozturk et al. (2010)	1970-2010	51 Countries	Pedroni Panel Cointegration Panel Causality Test	GDP ⟹ EC GDP⇔ EC
Pablo-Romero and De Jesús (2016)	1990-2011	22 Countries (Latin America and the Caribbean)	Cubic EEKC Specification	EEKC not supported.
Pao and Tsai (2010)	1971-2005	BRIC Countries	ECM	EEKC supported.
Rahman et al. (2020)	1981-2016	China	(FM-OLS) Hatemi-J Cointegration VECM	Long-Run: Coal, Oil, Gas ⟹ GDP
Richmond and Kaufmann (2006)	1978-1997	16 OECD Countries	Quadratic Specification Semi-Log Specification Double-Log Specification Augmented Dickey-Fuller (ADF)	Including energy prices in EEKC framework reduces support for EEKC hypothesis. EEKC not supported.
Riji et al. (2017)	1970-2015	China	ARDL FM-OLS Dynamic OLS	EEKC supported.
Saboori and Sulaiman (2013)	1980-2009	Malaysia	ARDL Johansen-Juselius ML VECM Granger Causality	EEKC not supported for aggregate EC. EEKC supported for coal, gas, oil and electricity. Long-Run: GDP⇔ CO_2 emissions.
Shahbaz et al. (2013)	1971-2011	China	ARDL Bounds Testing	EC ⟹ GDP Financial Development ⇔ EC International Trade ⇔ EC
Shahbaz et al. (2016)	1971-2012	India	ARDL Cointegration Test (Bayer-Hanck)	Globalisation leads to less energy demand. Financial Development ⟹ EC (negative). Long-Run: GDP ⟹ EC
Shahbaz et al. (2017a)	1820-2015	G7 Countries	Non-Parametric Cointegration and Causality Tests	EEKC supported in all countries except Japan.
Shahbaz et al. (2017b)	1960-2015	India	Non-Linear ARDL Bounds Testing. Asymmetric Causality Test.	Only negative EC shocks impact GDP.
Song et al. (2013)	1993-2010	China	Copeland Model	EEKC supported in provinces.

Table A1: Summary of the studies in literature review

Study	Time Period	Countries/Regions	Methodology	Results
Song et al. (2008)	1985-2005	China	Panel Cointegration Dynamic OLS Within OLS	EEKC supported.
Soytas and Sari (2003)	1950-1992	G7 Countries and Emerging Markets	Dickey- Fuller ADF Unit Roots	EC ⟹ GDP in Turkey, France, Germany and Japan GDP ⟹ EC in Italy and Korea EC ⇔ GDP in Argentina
Suri and Chapman (1998)	1971-1991	33 Countries	FE Model Feasible GLS	EEKC supported. Industrialized countries import manufactured goods to reduce EC.
Ululcak and Bilgili (2018)	1961-2013	15 Countries	CUP-FM Model CUP-BC Model	EEKC supported (High, Medium and Low Income Countries).
Voigt et al. (2017)	1995-2007	40 Countries	LMDI	Technological change a bigger driver of energy efficiency than structural change.
Wagner (2015)	1870-2000	10 Developed Countries	FM-OLS (Cointegration Polynomial Regression)	EEKC not supported.
Wang et. Al (2011)	1995-2007	China	Cointegration Analysis VECM	EC ⇔ GDP
Wang et al (2020)	2001-2016	China	Tapio Decoupling Model Causal-Chain Decomposition Model Grey Verhulst Model	GDP and CO_2 emissions have mostly weak decoupling in industrial steel industry.
Wolde-Rufael	1971-2004	17 Countries (Africa)	Multivariate Modified Granger Causality	Does not support neutrality hypothesis of EC-Income
Xu et al. (2014)	1996-2011	China	LMDI	GDP ⟹ Emissions
Yaguchi et al. (2007)	1975-1999	China and Japan	OLS (Fixed Effects) Cointegration ECM	EEKC supported for SO_2 emissions (Japan). EEKC not supported (China)
Yang et al. (2015)	1995-2010	China	Extreme Bound Analysis	EEKC not supported (all 7 pollutant indicators).
Yin et al. (2015)	1999-2011	China	GLS Estimator (Random Effects)	Supports EEKC for CO_2 emissions due to environmental regulation.
Zhang and Xu (2012)	1995-2008	China	Panel Unit Root Panel Cointegration Granger Causality	GDP ⟹ EC
Zhang et al. (2019)	1990-2016	China	Index Decomposition Analysis Decoupling Analysis	GDP ⟹ Electricity Consumption

Table A1: Summary of the studies in literature review				
Study	**Time Period**	**Countries/Regions**	**Methodology**	**Results**
Zhang et al. (2018)	1978-2014	China	ARDL	EEKC supported (10 provinces). EEKC not supported (20 provinces with no peak EC per capita).
Zhang et al. (2019)	2000-2014	China	LMDI Decoupling Analysis	Xinjiang: Industrial growth and CO_2 emissions went through stages of negative, weak and negative decoupling.
Zhang and Cheng (2009)	1960-2007	China	Augmented VAR (Toda and Yamamoto)	GDP ⟹ EC EC ⟹ CO_2 emissions CO_2 emissions and EC don't lead to GDP growth.
Zheng et al. (2018)	2011-2015	China	Data Envelopment Analysis	EC policies more effective in North West China and North East China than East China.

Note: ⟹ implies uni-directional causality, ⇔ implies bi-directional causality and ⇎ implies no causality.
GDP ⟹ EC implies that causality runs from growth to energy consumption. EC ⟹ GDP implies that causality runs from energy consumption to growth. EC ⇔ GDP implies bidirectional causality between growth and energy consumption. EC ⇎ GDP implies absence of causality between growth and energy consumption.