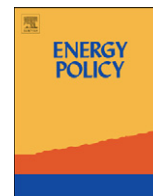Contents lists available at ScienceDirect

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CO$_2$ emissions, energy consumption and economic growth in China: A panel data analysis

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ABSTRACT

This paper examines the causal relationships between carbon dioxide emissions, energy consumption and real economic output using panel cointegration and panel vector error correction modeling techniques based on the panel data for 28 provinces in China over the period 1995–2007. Our empirical results show that CO$_2$ emissions, energy consumption and economic growth have appeared to be cointegrated. Moreover, there exists bidirectional causality between CO$_2$ emissions and energy consumption, and also between energy consumption and economic growth. It has also been found that energy consumption and economic growth are the long-run causes for CO$_2$ emissions and CO$_2$ emissions and economic growth are the long-run causes for energy consumption. The results indicate that China's CO$_2$ emissions will not decrease in a long period of time and reducing CO$_2$ emissions may handicap China's economic growth to some degree. Some policy implications of the empirical results have finally been proposed.

1. Introduction

There has been a growing concern on the global warming mainly arising from the huge amount of world-wide carbon dioxide (CO$_2$) emissions. A number of developed countries have committed to reduce their domestic CO$_2$ emissions to a certain level. As a major developing country and one of the largest CO$_2$ emitters, China is now facing great pressure on reducing its energy consumption and CO$_2$ emissions. In the past three decades, China's economy has gained rapid development via the path of "high energy consumption, high greenhouse gas emissions". In 2008, the total amount of energy consumption in China is 2850 million tonnes of coal equivalent (Mtce) of which fossil fuel took account of more than 90% (NBSC, various years). Meanwhile, the level of unbalance in economic development, energy consumption and CO$_2$ emissions among different regions in China was quite high (ERIPG, 2009). In 2008, several rich provinces such as Guangdong, Shandong and Jiangsu have GDP higher than 3000 billion Chinese Yuan while there are some provinces such as Ningxia, Qinghai and Hainan with GDP lower than 300 billion Chinese Yuan. The variation in unit GDP energy consumption between different regions is also high, which ranged from 6.62 in

Beijing to 36.9 tce per thousand Chinese Yuan in Ningxia in 2008 (NBSC, various years).

In the "Eleventh Five-Year Plan", China government set the target of reducing its unit GDP energy consumption by 20% by the end of 2010. Before the Copenhagen Climate Change Conference 2009, China State Council declared its goal to reduce its unit GDP CO$_2$ emissions by 40–45% by 2020, compared with 2005. This announcement signals China's domestic intent to achieve significant CO$_2$ emission reductions, while enhances its domestic pressure on reducing fossil energy consumption and CO$_2$ emissions. In the forthcoming "Twelfth Five-Year Plan", China government will likely set the clear targets for reducing its unit GDP energy consumption and unit GDP CO$_2$ emissions till 2015. As the per capita income in China is still quite low, China government will certainly take economic development as its primary task within a quite long period of time. To realize the targets of energy conversation and emission reduction while ensuring its economic development, China government needs to search for new development paths such as low-carbon development. On the other hand, the diversities among different regions in economic development and energy consumption must also be considered in establishing the targets of regional energy conservation and emission reduction or promoting regional and national low-carbon development. There is therefore a need to clearly understand the relationships between economic growth, energy consumption and CO$_2$ emissions based on the provincial panel data in China.

In literature, exploring energy–environment–economy nexus has attracted attention from researchers in different countries for a long

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Table 1
Summary of previous studies on the relationships between energy, environment and economy.

Study	Country	Period	Methodology	Causality
Energy–economy nexus				
Stern (1993)	USA	1947–1990	Multivariate VAR model	EC→GDP
Aqeel and Butt (2001)	Pakistan	1955–1996	Hsiao's version of Granger causality	GDP→EC
Squalli (2007)	11 OPEC countries	1980–2003	ARDL bounds test, Toda–Yamamoto procedure	Miscellaneous
Yuan et al. (2008)	China	1963–2005	Johansen–Juselius, VECM	EC (electricity, oil)→GDP GDP→EC (total energy, coal, oil)
Belloumi (2009)	Tunisia	1971–2004	Johansen–Juselius, VECM	EC↔GDP (in the long-run) EC→GDP (in the short-run)
Ghosh (2010)	India	1971–2006	ARDL bounds test, Johansen–Juselius, VECM	Miscellaneous
Environment–economy nexus				
Holtz-Eakin and Selden (1995)	130 countries	1951–1986	EKC hypothesis	Monotonic rising curve
Friedl and Getzner (2003)	Australian	1960–1999		N-shaped curve
Galeotti and Lanza (2005)	108 countries	1971–1995		Inverted U-shaped curve
Richmond and Kaufman (2006)	36 nations	1973–1997		No relationship
Energy–environment–economy nexus				
Ang (2007)	France	1960–2000	Johansen–Juselius, ARDL bounds test, EKC, VECM	EC→GDP Inverted U-shaped curve
Halicioglu (2009)	Turkey	1960–2005	ARDL bounds test, Johansen–Juselius, VECM	CO_2↔EC, CO_2↔Income CO_2↔Square of income Income↔ Square of income
Apergis and Payne (2009)	Six central American countries	1971–2004	Pedroni cointegration, EKC, panel VECM	EC↔GDP, EC→CO_2 GDP→CO_2 Inverted U-shaped curve
Ang (2009)	China	1953–2006	ARDL bounds test	Miscellaneous
Jalil and Mahmud (2009)	China	1975–2005	ARDL bounds test, EKC, VECM	Income→CO_2 Square of income→CO_2 Inverted U-shaped curve
Zhang and Cheng (2009)	China	1960–2007	Toda–Yamamoto procedure	GDP→EC EC→CO_2
Chang (2010)	China	1981–2006	Johansen cointegration VECM	Miscellaneous
Apergis and Payne (2010)	11 independent states	1992–2004	Pedroni cointegration, EKC, panel VECM	Miscellaneous
Lean and Smyth (2010)	Five ASEAN countries	1980–2006	Johansen Fisher panel cointegration EKC, panel VECM	CO_2→EC Inverted U-shaped curve

Note: EC refers to energy consumption, VAR represents vector autoregressive model, VECM denotes vector error correct model, ARDL refers to autoregressive distributed lag procedure and EKC refers to environmental Kuznets curve.

time. Roughly, past studies in this field may be divided into two lines of research (Soytas and Sari, 2009). The first focuses on the relationship between economic growth and energy consumption, which could date back to the pioneering work by Kraft and Kraft (1978). Since their study, Granger causality test approach has become a popular tool for studying the relationship between energy consumption and economic growth in different countries, e.g. Stern (1993), Aqeel and Butt (2001), Yuan et al. (2008) and Ghosh (2010). It is worth pointing out that most of the previous studies used a bivariate model to test the causality relationship, which suffered from the issue of omitted variables bias as pointed out by Stern (1993).

The second line of research focuses on the relationship between economic growth and environment, which is closely related to examining the inverted U-shaped relationship between environmental pollutants and economic growth, i.e. testing the validity of environmental Kuznets curve (EKC) hypothesis.[1] Researchers have carried out a large number of empirical studies in which different conclusions have been drawn. For instance, the studies by Selden and Song (1994) and Galeotti and Lanza (2005) provided empirical evidences on the validity of EKC hypothesis. However, Holtz-Eakin and Selden (1995) found a monotonic rising curve and an N-shaped curve was found by Friedl and Getzner (2003). On the other hand, Agras and Chapman (1999) and Richmond and

Kaufman (2006) concluded that there is no significant relationship between economic growth and environmental pollutants.

Most previous studies have shown that economic development would likely lead to changes in CO_2 emissions. It has also been found that energy consumption is often a key determinant of CO_2 emissions. It is therefore worthwhile to investigate the relationships between the three variables by considering them simultaneously in a modeling framework. In this line, Ang (2007), Apergis and Payne (2009, 2010), Lean and Smyth (2010) and Marvão Pereira and Marvão Pereira (2010) have done some good theoretical and empirical attempts.

Table 1 summarizes some earlier relevant studies with their main features including methodology employed and main findings. It can be seen from Table 1 that although several earlier studies, e.g. Zhang and Cheng (2009), Jalil and Mahmud (2009), Ang (2009) and Chang (2010), have investigated the case of China, all of them are based on the aggregate data at country level. It is therefore necessary to reexamine the relationships between CO_2 emissions, energy and real economic output in China by considering the differences of various regions in economic development and energy consumption. The purpose of this study is to use China's provincial panel data to conduct such an empirical analysis using the model proposed by Ang (2007) and the novel econometric approach given by Apergis and Payne (2009). It is expected that this analysis would add new insights into the existing literature, which could be useful to help formulate and implement carbon emission reduction policies.

The rest of this paper is organized as follows. Section 2 describes the model and data used in our empirical study. Section 3 provides a brief discussion of the panel unit root tests,

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[1] Grossman and Krueger (1991) first pointed out the existence of the inverted U-shaped relationship between pollutants and per capita income, which is followed by a large number of empirical studies on testing the validity of EKC hypothesis. Dinda (2004) provided an excellent and comprehensive review of the EKC literatures. Examples of recent EKC studies with CO_2 emissions included are Soytas et al. (2007), Jalil and Mahmud (2009) and Iwata et al. (2010).