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The Relationship between Energy Consumption and GDP Growth in China

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Abstract

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In the last 30 years, China has achieved rapid economic growth. Energy played important roles in supporting the development of China and now China become the largest energy consumer country in the world. Based on the time series data of energy consumption and GDP from 1978-2011 in China, we explored the relationship between energy consumption and GDP using ADF, co-integrate and VECM test. There were long run equilibrium relationships between GDP and energy consumption and the consumption of disaggregate categories of energy, such as coal, oil and electricity except gas; Moreover, two-way short term causalities running between GDP and energy consumption, coal and electricity consumption and one-way long term causality running from oil consumption to GDP were also founded. As a secondary contribution, we investigate the decoupling trend between GDP and the aggregate energy consumption. All the empirical results support the notion that although China economy still relied on the energy consumption, there is also weak decoupling trend. Finally, we gave policy implications upon the estimation results regarding current Chinese economy development policies, such as exploiting new energies and speeding up innovation.

Keywords: Co-integration; Error correction; Granger causality; GDP; Energy consumption; China

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Chapter 1 Introduction

The ongoing debate among energy economists about the relationship between energy use and output growth led to the emergence of two opposite views. One point of view suggests that energy is the prime source of value because other factors of production such as labor and capital cannot do without energy. According to this argument, energy use is expected to be a limiting factor to economic growth or its proxies such as employment. The other point of view suggests that energy is neutral to growth. The main reason for the neutral impact of energy on growth is that the cost of energy is very small as a proportion of GDP and, thus, it is not likely to have a significant impact on output growth. It has also been argued that the possible impact of energy use on growth will depend on the structure of the economy and the stage of economic growth of the country concerned. As the economy grows its production structure is likely to shift towards services, which are not energy intensive activities.(Denison, 1985; Solow, 1978).

In China, Energy plays an important role in the economy's sustainable development. In the past two decades, China has achieved rapid economic growth. Updated statistics showed China has been the largest energy consumer country replacing the United States in the world (China National Energy Bureau, 2012). Historically, the energy was designated as a driving force of China's economic growth. In line with the rapid expansion of the Chinese economy after the late 1970s, there has been an increasing demand for energy. The consumption of primary energy has also been increasing continuously, even with an annual growth rate of 10.9% during the 2003-2007 periods. The total energy consumption amount has magnified by approximately 3.5 times from7.67×10^8 tons of SCE in 1992 to 26.56×10^8 tons of SCE in 2007, accordingly one-off energy consumption including coal, crude oil and natural gas had a rising trend wholly. The coal consumption in China accounts for approximately 69.5% of the total primary energy consumption in 2007 and 70.7% in 1978, only decreased by about 1.2%, which is over 4 times more than the average level in developed countries. The development of hydro-electric power, nuclear power and wind power is slow, rose by only 3.9% from 3.4% of the total energy consumption in 1978 to 7.3% in 2007. At present, the Chinese government has a policy target of achieving a sustained growth rate of 8% per year. This implies that total output will be doubled every 10 years. The study of the causal relationship between energy consumption and GDP will help us better understand the role of energy in China's economic growth. The results of causality tests can shed light on future energy policies, such as conservation programs, the energy exploiting innovation. Therefore, it is important to understand the relationship between energy and GDP.

In the past two decades, there has also been a growing interest in the study of the causal relationship between energy consumption and economic growth. Different studies have focused on different countries, time periods, proxy variables and different econometric methodologies have been used for energy consumption and growth relationship. The empirical outcomes of these studies have been varied and sometimes found to be conflicting. The results seem to be different on the direction of causality and its long-term versus short-term impact on energy policy. The policy implications of these relationships can be significant depending upon what kind of causal relationship exists. The directions that the causal relationship between energy consumption and economic growth could be categorized into four types each of which has important implications for energy policy: two-way causality relationship; one-way causality relationship; different relationships among different economic entities, or during different periods within one country; no causality relationship between GDP and Energy. The majority of the studies on the relationship between energy consumption and the economic growth concentrated in the fixed parameter model, and used the co integration test and Error Correction Model (ECM), to testify that there is a long-term equilibrium relationship between them. However, with the time varying and the economic structural changes in domestic and foreign countries, a certain relationship between the two variables is likely to change as well. Forecasts of the relationship between the growth in China's energy consumption and GDP are important for two reasons. First, continuation of the strong growth in energy consumption in recent decades will see underlying demand and supply imbalances in China, increasingly affecting global energy markets, particularly oil and natural gas. Second, long-term forecasts are required to assess the need for future trade and investment strategies to ensure the security of China's energy supply. This paper re-examines the causality between energy consumption and GDP by using updated China data for the period 1978-2011. As a secondary contribution, investigating the causal relationship between GDP and the aggregate as well as several disaggregate categories of energy consumption, including coal, oil, natural gas, and electricity. Using ADF, co-integrate and VECM test. I found: the causality test shows that the causality relationship from GDP to energy consumption is not clear at 5% significance level, but there exists one-way causality relationship from the long-term energy consumption to the GDP. Further, we find that different directions of cause exist between GDP and various kinds of energy consumption.

The remainder of this study is structured as follows. In section 2, the previous literature related to the relationship between GDP and energy consumption were summarized; in section 3, the energy consumption general background was reviewed; in section 4, present the theoretical background and describe the data and develop the empirical analysis; Section 5 presents the results and discussions; Based on the estimation results, conclusion and policy implications on the current energy consumption policy system are discussed in Section 6; Finally, Section 7 shows some limitations and arguments in terms of future research.

Chapter 2 Literature Review

The topic of causal relationship between energy consumption and growth has been well-studied in the energy economics literature. Different studies have focused on different countries, time periods, proxy variables and different econometric methodologies have been used for energy consumption and growth relationship. The empirical outcomes of these studies have been varied and sometimes found to be conflicting. The results seem to be different on the direction of causality and its long-term versus short-term impact on energy policy. The policy implications of these relationships can be significant depending upon what kind of causal relationship exists.

The study of the causal relationship between energy consumption and economic growth started with the seminal work of Kraft and Kraft (Kraft & Kraft, 1978), in which causality was found to run from GNP to energy consumption in the United States. Empirical studies were later extended to cover other industrial countries like the United Kingdom, Germany, Italy, Canada, France, and Japan (Erol & Yu, 1987; Yu & Choi, 1985) .

These diverse results arise due to the different data set, alternative econometric methodologies and different countries' characteristics. The actual causality is different in different countries and this might be due to different countries' characteristics such as different indigenous energy supplies, different political and economic histories, different political arrangements, different institutional arrangements, different cultures and different energy policies, etc.(Chen, Kuo, & Chen, 2007). As pointed out also by Karanfil (Karanfil, 2008), in developing countries, mainly due to the unrecorded economic activities the official GDP is not measured correctly, the investigation of the linkage between energy consumption and official GDP may not give reliable results.

The directions that the causal relationship between energy consumption and economic growth could be categorized into four types each of which has important implications for energy policy (Apergis & Payne, 2009; Chen et al., 2007; Squalli, 2007):

2.1 Two-way Causality

There is a two-way causality relationship between GDP and EC, exists a long run equilibrium. It is also called ‘‘feedback hypothesis’’. It implies that energy consumption and economic growth are jointly determined and affected at the same time. Yang applied Engle-Granger two steps methods and found that there is a two-way causality relationship between GDP and EC in Taiwan, although there is a one-way relationship from GDP to Coal consumption (Yang, 2000a, 2000b). Stern applied the co-integration model and extended his research results in 1993 and found that there is long run equilibrium among GDP, capital, labor and EC. Glasure found that there is a two-way causality relationship between GDP and EC(Glasure, 2002). Ghali applied Johansen method and found that there is a two-way causality between Production and EC in Canada(Ghali & El-Sakka, 2004). Oh, Lee and Mahadevan found that there is a two-way causality between EC and GDP (Lee, 2006; Mahadevan & Asafu-Adjaye, 2007; Oh & Lee, 2004).

2.2 One-way Causality

There is a one-way causality relationship from GDP to EC and from EC to GDP. Kraft used US GDP and EC data (1947-1974), Yu and Hwang used data (1973-1981) as sample to analyze, and found that there is a one-way causality from GDP to EC (Kraft and Kraft, 1978;Yu and Hwang, 1984). Abosedra and Baghestani chose US GDP and EC different period data (1947-1972, 1947-1974, 1947-1979, 1947-1987) as sample, the results are the same, that is, no matter when the data was be chose, there is always a one-way causality from GDP to EC (Abosedra and Baghestani, 1991). Stern applied the VAR four varaibles regression model to analyz US GDP and EC data(1947-1990), and found that there is a one-way causality from EC to GDP (Stern, 1993). Lee concluded that there is a one-way causality from EC to GDP both in a short term and long run among 18 developing countries (Lee, 2006). Mozumder found that there is a one-way causality from GDP to electricity in Bengal (Mozumder and Marathe, 2007).

2.3 Different Relationships

There are different relationships among different economic entities, or during different periods within one country. Yu and Choi proposed that there are different relationships among different countries, there is no causality relationship between the GDP and EC, such as US, UK and Polland, however, there is one-way causality relationship in Korea and Philippine (Yu & Choi, 1985). After surveying 11 developing countries and 5 developed countries, Nachane and Kamik found the co-integration relationship between GDP and EC. Masih found that there is no co-integration relationship between GDP and EC in some Asian countries, such as Korea, Taiwan, India, Pakistan and Indonesia. However, in Malaysia, Singapore, Philippine and Thailand there is no this kind of relationship (Masih & Masih, 1996, 1997, 1998). Using Johansen test, Aasfu-Adjaye found there is one-way causality relationship from EC to income in India and Indonesia and there is two-way causality relationship between EC and income in Philippine and Thailand (Asafu-Adjaye, 2000). Fatai found that there is a one-way causality relationship from GDP to EC in New Zealand and Australia, and from EC to GDP in Indonesia, whereas, there is a two-way causality relationship between GDP and EC due to the lower energy consumption density (Fatai, Oxley, & Scrimgeour, 2004). After researching 30 OECD countries and 78 non-OECD countries, Chontanawat found there is a significant one-way causality relationship from EC to GDP, especially in developed countries (Chontanawat, Hunt, & Pierse, 2006). Lee and Chang applied the 16 Asian countries Panel data and found that there is no causality relationship between EC and GDP in a short term, however, there is a one-way causality relationship from EC to GDP in a long run(Lee & Chang, 2008).

2.4 No Causality

Akarca and Long doubted Kraft's conclusion and proposed that Kraft chose the inappropriate data as the sample during the oil crisis period so that his results was not credible(Akarca & Long, 1979). Yu and Hwang used the US(1947-1997) GDP and EC data as sample and found that there is no causality relationship from GDP to EC(Yu & Hwang, 1984). Masih, Achla Marathe found that there is no causality relationship between GDP and EC(Masih & Masih, 1996; Mozumder & Marathe, 2007).

The majority of the studies on the relationship between energy consumption and the economic growth concentrated in the fixed parameter model, and used the co integration test and Error Correction

Model (ECM), to testify that there is a long-term equilibrium relationship between them.

2.5 China Domestic Literature

In recent ten years, China domestic researches mainly focused on co-integration and causality relationship between GDP and aggregate energy consumption or between GDP and electricity consumption, applying for VAR, Granger causality models.

Lin boqiang found that there is a one-way causality relationship from electricity consumption to GDP in a long term, however, they are fluctuating in a short term(B. Lin, 2003). Wu qiaosheng and Liu xing found that there is one-way causality from GDP to aggregate energy consumption(WU, CHENG, & Wang, 2005; Xing, 2006). Han zhiyong found that there is two-way causality between GDP and aggregate energy consumption, however there is no co-integration relationship (Han, Fan, & Wei, 2004).

However, with the time varying and the economic structural changes in domestic and foreign countries, a certain relationship between the two variables is likely to change as well. The purpose of this paper is to re-examine the causality between energy consumption and GDP by using updated China data for the period 1978--2011.

Table 1 Overview of main methodologies of causality on energy consumption and GDP

Methodology	Authors	Data samples	Causality relationship
Granger causality	Kraft and Kraft(1978)	1947-1974,USA	GDP⟶EC
	Yu and Choi(1985)	1950-1976,Korea, etc	GDP- - -EC(UK,USA, Poland) EC ⟶ GDP(Philippines) GDP⟶EC(Korea)
	Erol and Yu(1987)	1952-1982,6 countries	EC⟵⟶GDP(Japan) GDP⟶EC(Italy, Germany) EC ⟶ GDP(Canada) GDP- - -EC(France, UK)
	Cheng and Lai(1997)	1954-1993,Taiwan	GDP⟶EC
	Cheng(1998)	1952-1995,Japan	GDP⟶EC
	Jobert and Karanfil(2007)	1960-2003,Turkey	GDP- - -EC
	Altinay and karagol(2004)	1950-2000,Turkey	GDP- - -EC
	Bowden and Payne(2009)	1949-2006,USA	EC ⟶ GDP
	Zhang and Cheng(2009)	1960-2007,China	GDP⟶EC
Co-integration	Lise and Van Montfort(2007)	1970-2003,Turkey	GDP⟶EC
	Mehrara(2007)	1971-2002,11 countries	GDP⟶EC
Multivariate	Stern(1993)	1947-1990,USA	EC ⟶ GDP
Error correction Model(ECM)	Hondroy iannis et al.(2002)	1960-1996,Greece	EC⟵ ⟶GDP
	Mahadevan and Asafu-Adjaye(2007)	1971-2002,20 energy im(ex)porters	EC⟵⟶GDP (developed countries) EC ⟶ GDP(in the

			short run for developing countries)
Co-integration and Granger causality	Abosedra and Baghestani(1989)	1947-1987,USA	GDP⟶EC
	Yu and Jin(1992)	1974-1990,USA	GDP- - -EC
	Nachane et al.(1988)	1950-1985,16 countries	EC⟵ ⟶GDP(except Venezuela and Colombia)
	Cheng(1995)	1947-1990,USA	GDP- - -EC
	Glasure and Lee(1997)	1961-1990, Korea, Singapore	GDP- - -EC(Korea) EC ⟶ GDP(Singapore)
	Stern(2000)	1948-1994,USA	EC ⟶ GDP
	Asafu-Adjaye(2000)	1971-1995,Phillipine,Thailand	EC⟵ ⟶GDP
	Soytas et al.(2001)	1960-1995,Turkey	EC ⟶ GDP
	Aqeel and Butt(2001)	1955-1996,Pakistan	GDP⟶EC
	Paul and Bhattacharya(2004)	1950-1996,India	EC ⟶ GDP
	Karanfil(2008)	1970-2005,Turkey	GDP⟶EC
	Erdal et al.(2008)	1970-2006,Turkey	EC⟵ ⟶GDP
	Halicioglu(2009)	1960-2005,Turkey	GDP- - -EC
Co-integration and Error correction	Hwang and Gum(1991)	1961-1990,Taiwan	EC⟵ ⟶GDP
	Glasure(2002)	1961-1990,Korea	EC⟵ ⟶GDP
	Lee and Chang(2005)	1954-2003,Taiwan	EC ⟶ GDP
	Ang(2007)	1960-2000,France	EC ⟶ GDP(in a short term)
	Ho and Siu(2007)	1966-2002,Hong Kong	EC ⟶ GDP
	Lee and Chang(2008)	1971-2002,16 Asia countries	EC ⟶ GDP(in the long run) GDP- - -EC(in the short term)
	Apergis and Payne(2009a)	1980-2004,6 countries	EC ⟶ GDP
	Ang(2008)	1971-1999,Malaysia	GDP⟶EC
Co-integration, VECM, Granger	Cheng(1999)	1952-1995,India	GDP⟶EC
	Ghali and El-Sakka(2004)	1961-1997,Canada	EC⟵ ⟶GDP

causality	Masih(1996)	1955-1990,6 Asian countries	EC ⟶ GDP(India) GDP⟶EC(Indonesia) EC⟵ ⟶GDP(Pakistan) GDP- - -EC(Malaysia, Philippines, Singapore)
	Lee and Chang(2007a)	1955-2003,Taiwan	EC ⟶ GDP(only where there is a low EC in Taiwan)
	Zamani(2007)	1967-2003,Iran	GDP⟶EC
Granger causality, VECM	Belloumi(2009)	1971-2004,Tunisia	EC⟵ ⟶GDP(in the long run) EC ⟶ GDP(in the short run)
	Asafu-Adjaye(2000)	1973-1995,India,Indonesia	EC ⟶ GDP

Note: EC⟶GDP means that the causality runs from energy consumption to growth.

GDP⟶EC means that the causality runs from growth to energy consumption.

EC⟵ ⟶GDP means that bi-directional causality exists between energy consumption and growth.

EC- - - -GDP means that no causality exists between energy consumption and growth.

Abbreviations are defined as follows: VAR=vector auto regressive model, VEC=vector error correction model, ARDL=auto regressive distributed lag, EC=energy consumption, GDP=real gross domestic product. ECM=error correction model.

Chapter 3 Energy Consumption in China

3.1 Energy Industry History

In China, energy industry started from the electric power industry in 1882, with the establishment of the country's first generation plant in Shanghai. The industry has gone through slow expansion in early years, with most power generating units operating in small capacity with low thermal efficiency. Since most of these power generating units were concentrated in a few big cities along the coastal regions, power supply in the interior provinces was limited. It was after 1949 that the Chinese government started to place greater emphasis on developing the energy industry and the process has gone through different stages. The years from 1949 to 1951 were a period of rehabilitation and reconstruction. Major energy infrastructure facilities, such as electric power and transport systems, were revamped (Dorian, 1998). In late 1952, the government decided to undertake long term economic planning, and adopted the Soviet model of development. During the first and second Five-Year Plans (1953-1957 and 1958-1962), heavy industries were put in a strategic position. In order to facilitate the development of heavy industries, coal, oil and electricity prices were kept low. Great efforts were made to expand the electric power industry, and to build large generating equipment. As a result, the electricity elasticity, that is, the growth rate of electricity generation relative to the growth rate of real GDP, was generally greater than one. The shortfall in coal supply had repercussions throughout other industries, particularly the electric power and iron and steel industries. Consequently, the electric power industry did not expand as expected during the third and fourth Five-Year Plans (1966-1970 and 1971-1975). Energy shortages continued throughout the 1970s, and this had an adverse effect on the outputs of other industries.

After the death of Chairman Mao in 1976, the Chinese government introduced a 10-year economic plan. The plan was originally intended to cover the fifth and sixth Five-Year Plan periods (1976-1980 and 1981-1985), with the principal goals of recouping the economic losses suffered during the previous years of turmoil, and accelerating the growth of China's economy. The plan aimed to build up China's industrial capacity, and to enable the country to achieve an industrial ranking on a par with other advanced countries by the turn of the century. However, the plan later proved to be impracticable, and a three-year adjustment plan (1979 – 1981) came into effect. This adjustment also marked the emergence of a series of major economic, political, and social reforms. China adopted an open door policy in 1978, and the sixth Five-Year Plan was drafted in accordance with this policy. The Chinese government encouraged foreign capital, technology, and joint ventures that could assist the country's modernization. The policy of opening up China to foreign countries continued into the seventh, eighth, and ninth Five-Year Plans (1986-1990, 1991-1995 and 1996-2000). Structural reforms, market incentives, and decentralization policies were introduced to attract foreign investment in the energy sector and the sector started rapid growth since the late 1980s. Despite the remarkable growth in the coal, oil and electric power industry in the last few decades, the speed did not keep up to pace with the country's economic growth. From historical data, it is found that there has been a decoupling of energy consumption and economic growth in China, which means the rate of growth of energy consumption, is no longer a direct one-to-one correlation with the growth in GDP. In particular, after the adoption of the open door policy in 1978, China's energy sector has not expanded as fast as the whole economy. The growth of capital investment in the energy industry lagged behind economic growth. However, during the same period, demand for electricity in China increased tremendously, when the economy developed and the living standard of the people was improved. This results in a persistent supply-demand gap in the energy sector. Apart from the capital constraint in the expansion of electricity supply, there are other possible reasons for the decoupling of energy consumption and economic growth, such as improvement in energy efficiency and energy conservation. I would consider the decoupling issue again in the last section, after reporting the empirical findings of our study.

3.2 Energy Consumption in China

With a population exceeding 1.3 billion and economic growth over the past two decades averaging around 8% (following market reforms commencing in the late 1970s), China's demand for energy has surged to fuel its rapidly expanding industrial and commercial sectors as well as households experiencing rising living standards. Today, China is the largest consumer of energy products in the world beyond the United States, consuming annually around 1.7 billion tons coal equivalent of energy. In 2003, China accounted for 31% of the world's coal consumption, 7.6% of oil consumption, 10.7% of hydroelectricity consumption, and 1.2% of gas consumption. Furthermore, China's global consumption share of all four energy fuels has increased sharply in recent decades. For example, in 1985, China's global shares were 20.7% for coal, 3.2% for oil, 0.7% for gas, and 4.6% for hydroelectricity[1]. Indeed, growth in energy consumption has been so strong since the early 1980s that it has outpaced growth in domestic energy supply, leading to a substantial expansion in China's energy imports, mainly oil.

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[1] Calculated from BP Statistical Review of World Energy (2004)

The heavy reliance on coal in China is due to abundant domestic stocks of coal, the tight control of commodity prices, and resultant underpricing of coal products during the central planning era and a lack of environmental awareness for many decades. Today, following two decades of rapid economic growth and rising demand for energy products, China's citizens are becoming more environmentally aware. As a result, Chinese policy makers have begun acknowledging the need to resort to cleaner sources of energy, particularly natural gas and hydroelectricity. Continued movement in this direction should see the share of coal in China's total energy consumption decline further, with the share of oil, gas, and hydroelectricity increasing substantially.

Continued growth in energy consumption and changes in the composition of energy use away from coal raises important issues for the security of China's energy supply. In 2003, China had 114.5 billion tons of coal reserves; some 11.6% of the world's proven recoverable reserves, suggesting a reserves-to-production ratio of 69 years[2]. The majority of these reserves are steaming coal suitable for electricity generation. The supply of alternate fuels, however, is less secure. In 2003, China's imports of oil reached 128.3 million tons, or around 46% of domestic oil consumption, following growing energy demand/supply imbalances as domestic supply struggled to keep pace with demand.

[2] BP Statistical Review of World Energy (2004)

Despite a heavy reliance on imports, China is the world's fifth largest oil producer and is currently searching for new reserves in China's remote country's northwest and offshore in the South China Sea. Natural gas reserves in China are plentiful, yet supply is currently restricted by inadequate gas distribution infrastructure. Furthermore, gas prices in China are set by the government at levels that make it difficult for gas to compete with coal on a cost basis. The final major alternate energy source is hydroelectricity, of which China has the world's largest potential, estimated at 675 GW, yet only 290 GW are commercially viable, with less than one quarter currently exploited (Yi-Chong, 2006).

Total energy consumption in China increased from 54 MtCE in 1953 to 1389 MtCE in 1996, an average annual growth rate of 8.9% (see Fig.1). Despite the continuation of strong growth in GDP, energy consumption fell unexpectedly in 1997 to 1377 MtCE, and by 1999 had fallen to 1301 MtCE, sparking fears of a permanent structural shift in Chinese energy consumption. By 2001, however, consumption in China had recovered to 1349 MtCE and by 2003 had risen further to 1678 MtCE. Of this, coal consumption accounted for 67% of total consumption. Oil was the next most important energy source, accounting for 23%, while natural gas and hydroelectricity accounted for 3% and 7%, respectively (Fig.2).

China's energy consumption since 1978 has several distinct characteristics. First, growth in energy consumption has been accompanied by a dramatic decline in energy intensity of use (i.e., energy consumption per unit of GDP) over the last two decades (see Fig. 3, 4). This change is even more obvious in an international context. When China initiated its economic reform program in the late 1970s, China's energy intensity was double that of the United States and triple that of Japan (see Fig.5). By 1999, China's energy intensity had fallen to levels more comparable to that of the United States and Japan. Technical and structural changes have been identified as the main factors that caused the fall in energy intensity in China[3]. It can also be argued that the fall in end-use energy intensity is partially the result of an improvement in energy efficiency and development of new materials(Galli, 1998; Sinton & Fridley, 2000). These explanations have also been supported by a recent study involving firm-level data (Fisher-Vanden et al., 2004).

Second, the composition of energy consumption in China is unbalanced in comparison with other countries (see Table 2). This is highlighted by the large domestic market share of coal in China, although its dominance has declined in recent years. Furthermore, the role of

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[3] See, for example, Kambara (Kambara, 1992), Huang(Huang, 1993), Lin and Polenske(X. Lin & Polenske, 1995), Garbaccio et al.(Garbaccio, Ho, & Jorgenson, 1999), and Fisher-Vanden et al. (Fisher-Vanden, Jefferson, Liu, & Tao, 2004).

natural gas is trivial. This situation has imposed a high cost on the economy in terms of environmental damage associated with excessive use of coal. As a result, the energy industry and policy makers are under tremendous pressure to change the structure of energy consumption and shift from coal to cleaner products such as natural gas and hydroelectricity.

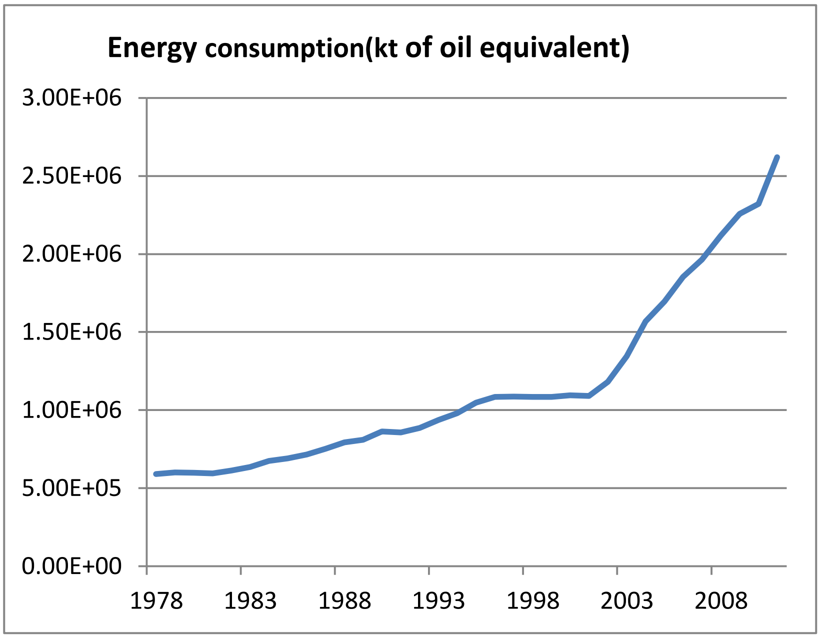

Fig. 1. Total energy consumption in China, 1978–2011 (State Statistical Bureau, various issues)

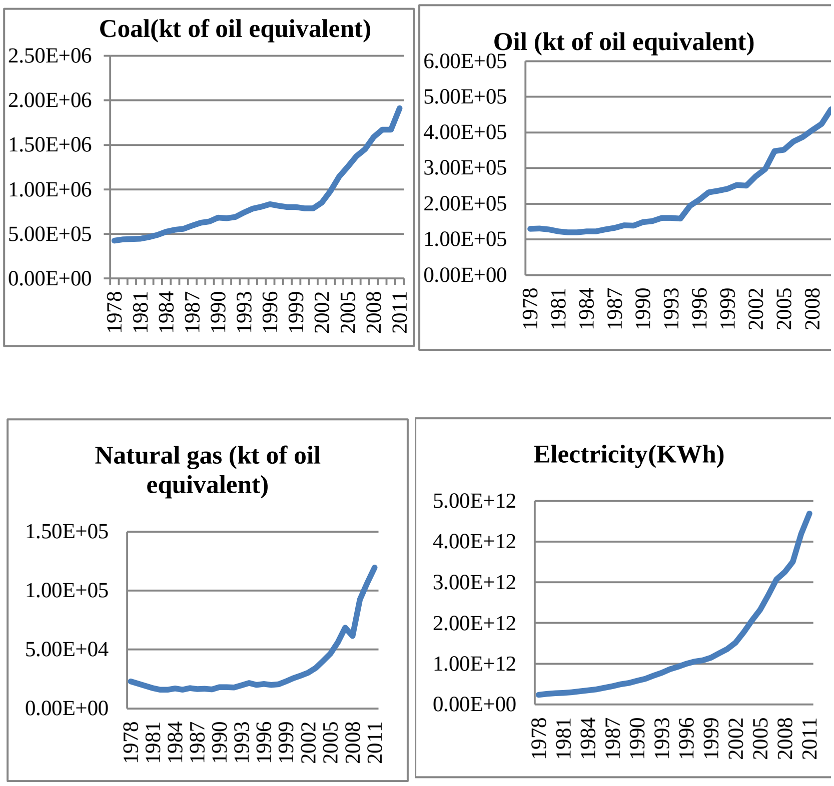

Fig. 2. Coal, oil, gas, electricity consumption in China, 1978–2011

(State Statistical Bureau, various issues)

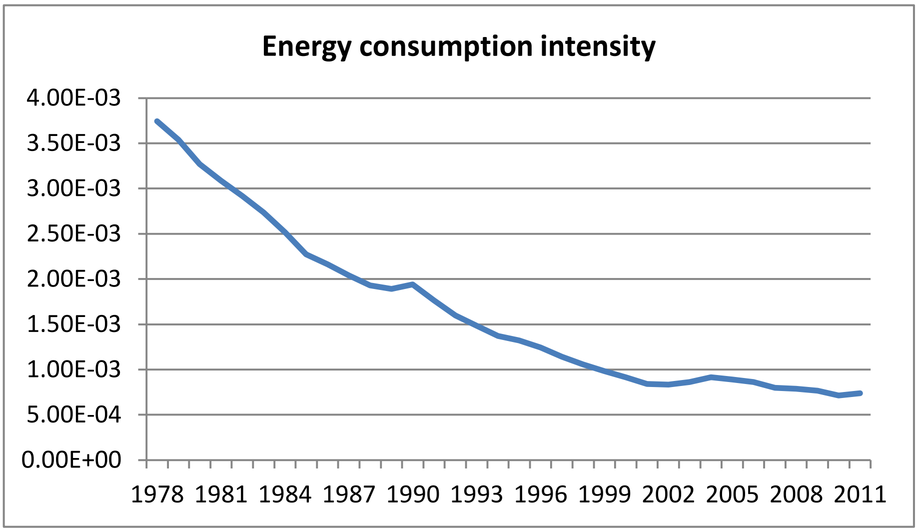

Fig. 3. Energy consumption intensity of use in China, 1978–2011 (calculated from State Statistical Bureau, various issues).

Note: Intensity of use in tons coal equivalent per US dollar measured at 2000 constant prices.

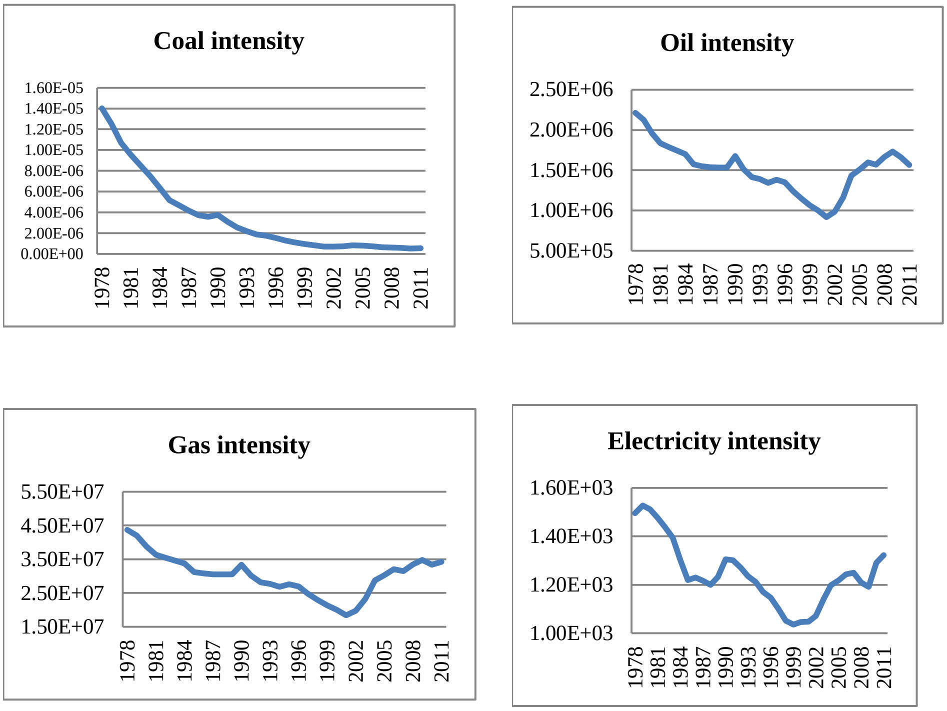

Fig. 4. Coal, oil, gas, electricity consumption intensity of use in China, 1978–2011 (calculated from State Statistical Bureau, various issues).

Note: Intensity of use in tons coal equivalent per US dollar measured at 2000 constant prices.

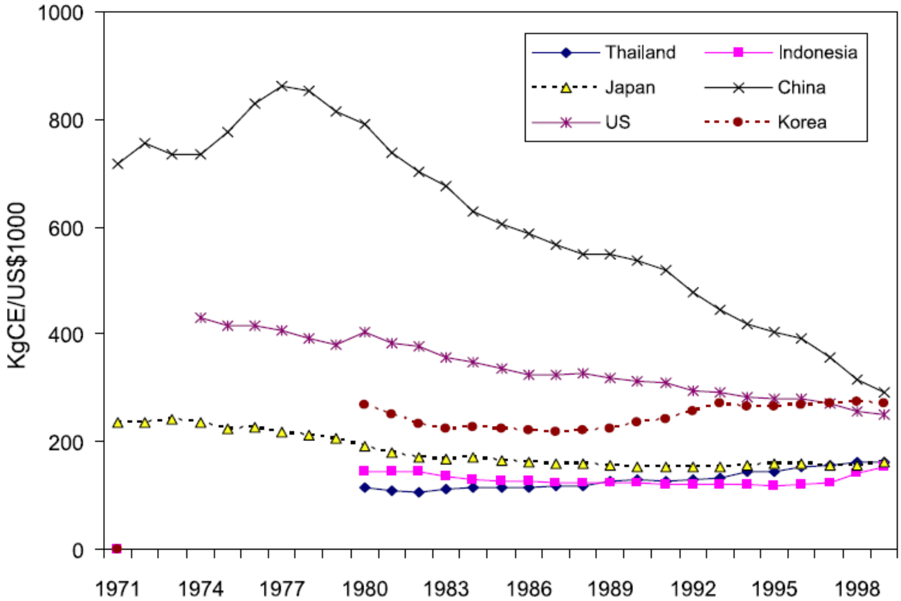

Fig.5. Energy intensity of use in selected countries, 1971–1999 (calculated from World Bank, 2002; APEC, 2002).

Table 2 Composition of energy consumption in selected countries

(percentage shares)

	2010	1996					
	China	China	US	Japan	India	Russia	Korea
Coal	71.9	74.7	24.2	17.6	56.9	19.7	19.2
Oil	20.0	18.0	39.1	53.8	31.9	21.1	61.6
Gas	4.6	1.8	26.7	11.9	7.9	52.4	7.4
Other	3.5	5.5	10.0	16.7	3.3	6.8	11.8

Source: Keii, C., 2000. China's energy supply and demand situations and coal industry's trends today (2000) and State Statistical Bureau (2010)

Third, although China's energy consumption is large in absolute terms, energy consumption per capita of about 0.5 ton oil equivalent (TOE) in 2001 is very small relative to that in the developed economies (e.g., 5.4 TOE in the United States, 3.0 TOE in Germany, and 2.7 TOE in Japan during the same period). This difference implies great growth potential in energy demand in China.

Fourth, energy consumption in China is highly unbalanced between the rural and urban sectors as well as across the Chinese provinces. In 2009, for example, urban energy consumption of 1.38 TCE per capita was much greater than rural consumption of 0.83 TCE[4]. The disparity in per capita energy consumption across China's provinces is highlighted in Table 3. For example, electricity consumption in Guangdong province is between three and five times higher than in China's developing provinces. Provincial and rural-urban energy consumption patterns in China, however, can be expected to change in response to changes in income distribution patterns. Over time, as regional income disparity narrows, rural consumers will catch up with their urban counterparts and poor areas with rich regions. This catching-up effect will also affect China's overall energy demand in the future.

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[4] Calculated using population and energy consumption data from State Statistical Bureau (2002) and Editorial Board (2001)

Table 3 Energy consumption per capita, 2009

	Coal(10000T	**oil**(10000to	**Gas**(100milli	**Electricit**	**Total**
Developed provinces					
Beijing	2665	1162.93	69.40	758.85	6570
Tianjin	4120	844.64	18.12	567.92	5874
Shanghai	5305	1937.18	33.52	1153.38	10367
Jiangsu	21003	2661.44	63.43	3313.98	23709
Zhejiang	13276	2505.80	19.30	2471.44	15567
Shandon	34795	5142.90	40.24	2941.07	32420
Fujian	7109	706.01	8.49	1215.51	8916
Guangdo	13647	3709.44	112.86	3609.64	24656
Developing provinces					
Anhui	12666	454.13	9.77	952.30	8896
Guangxi	5199	163.03	1.21	856.29	7075
Guizhou	10912	0	4.18	750.30	7566
Yunnan	8886	0.07	4.52	891.19	8032
Shanxi	27762	0	13.76	1267.54	15576

m3=cubic meters; KW h=kilowatt hours; TCE=tons coal equivalent.

Sources: State Statistical Bureau (2010) and China Energy Statistical Yearbook (2010).

Finally, China's energy demand has also been influenced by the growth in demand for energy-intensive products such as automobiles and air conditioners. The number of registered motor vehicles in China has increased from 6.2 million in 1990 to 2 billion in 2011 (State Statistical Bureau, 2011). The ownership of air conditioners in China's urban households has increased from 11.6% in 1990 to 94.8% in 2009 (State Statistical Bureau, various issues, 2010).

These features of China's energy consumption imply that strong growth in energy demand will continue in the future. This growth is likely to be sustained due to the expected continued expansion in the Chinese economy, with an average rate of economic growth in the coming decade projected to be about 7% (World Bank, 1997). Currently, China is heading into its next cycle of high growth following the downturn in the late 1990s.

China, with a share of 12.1% of the world's total energy consumption, is already a significant player in the global energy market[5]. In 2009, imports of crude oil of 2 billion (104 TCE) accounted for about 43% of the country's total oil supply (i.e., production plus imports)[6]. Since 2002, China has signed a 25-year contract to import annually 3 million tons of liquefied natural gas from Australia. Further growth in China's

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[5] Computed using statistics from the International Energy Agency (www.iea.org) and from the State Statistical Bureau (2003)

[6] According to the State Statistical Bureau (2010)

domestic energy consumption will have important implications for the world energy industry. This makes analyzing energy consumption in China an important contribution to the field.

3.3 Energy Consumption Economy and Policies

3.3.1 Energy Economy

From the perspective of energy economics, the growing consumption of energy in China poses an academic puzzle as well as a practical challenge. Aggregate Chinese energy demand has increased at an average annual rate of 3% annually from 1980 to 2009 and showed lightly increase recent years (see Fig.6). With GDP growing in the 7 to 11% range, one might anticipate that Chinese energy demand would rise more rapidly than it has. It is probable that growing needs for motor fuel will increase China's energy needs more rapidly in the future than in the past. China's rapid economic growth has been accompanied by drastic changes in the country's energy economy. And some kind of a country are in “energy transition”.[7] The ongoing changes have various dimensions: from a user of low efficiency solid fuels to higher efficiency gaseous and liquid fuel and electric power, from a

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[7] For a summary discussion see Energy Information Agency, 2005. Country Analysis Briefs: China. http://www.eia.doc.gov/emeu/tabs/china.html.

predominantly agricultural economy to increasing urbanization and industrialization, from heavy industry to lighter and, increasingly, high technology industry, from a country with low motorization to rapid growth of the motor vehicle population, from a country that was largely energy self-sufficient to a significant petroleum importer.

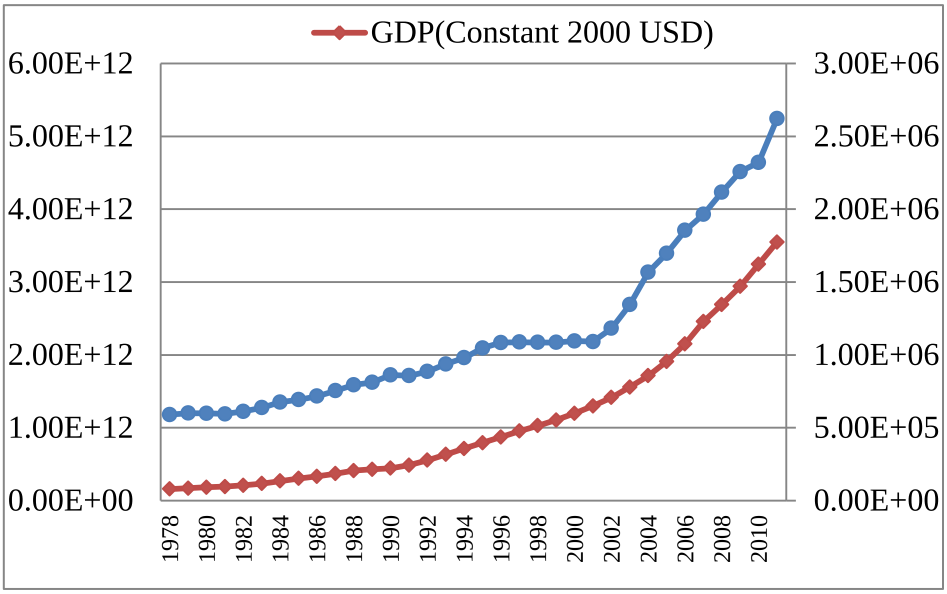

Fig. 6. Energy consumption and GDP, 1978–2011 (came from World Bank, based on per US dollar measured at 2000 constant prices).

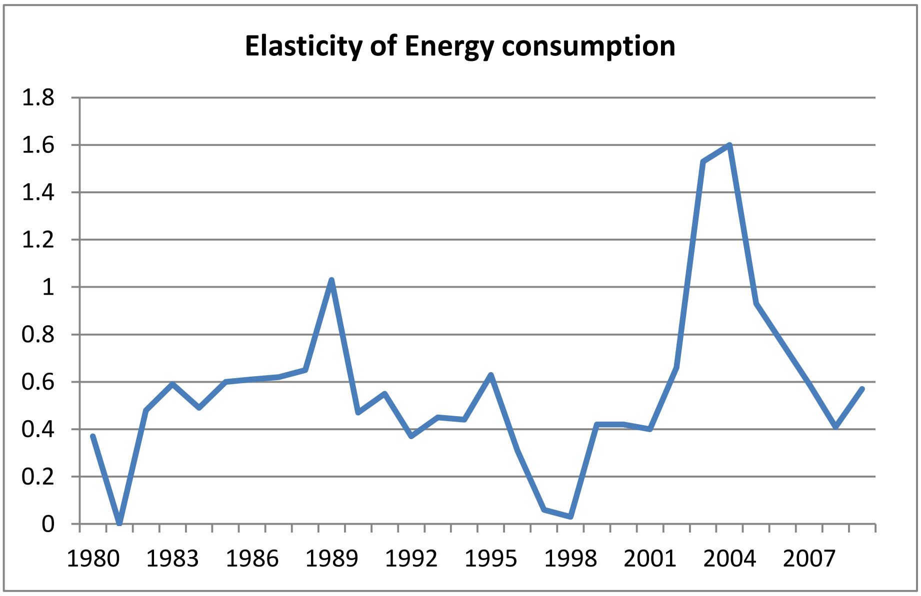

Fig. 7. Elasticity of energy consumption, 1980–2009 (came from China Energy Statistical Yearbook, 2010).

Energy consumption in China has shown growth, except in the 1995-2002 period, but, given the rapid growth of GDP, The aggregate energy demand elasticity with respect to GDP was 0.31until 1996 and averaged 0.57 over the entire 1980-2009 period (Fig.7).[8] This contrasts sharply with the typical expectation that the energy elasticity in developing countries exceeds unity, in other words, energy consumption rises proportionately more rapidly than GDP (Zilberfarb & Adams, 1981). This can be explained by changes in the composition of production and the energy intensity of production (Brookes, 1972; Soligo & Jaffe, 1999) and by substitution between fuels(Adams & Miovic, 1968).

In the 1996-2002 years, the computed energy elasticity is only 0.04 and the relationship between growth of GDP and energy consumption is not statistically significant. As we shall see, China represents a special case, reflecting the initial heavy use of coal and waste materials. Unless one discounts China's rapid GDP growth, a low aggregate elasticity must reflect sharp gains in the efficiency of energy use. In view of the pattern of the energy elasticity of China, reflecting the transitional nature of the

[8] The discrepancy between Chinese growth and energy consumption has caused a number of scholars to raise questions about Chinese national accounts statistics(Adams & Chen, 1996; Rawski, 2001). In this connection one of the authors can report an illuminating episode. In the early 1990s, presenting a lecture to students in Tianjin, Adams mentioned the elasticity linking demand for energy and GDP. A hand quickly shot up. The student explained that, "Of course, the energy elasticity in China is 0.5, just like in the United States!"

Chinese energy economy, it is not useful to rely on an aggregate elasticity to forecast Chinese energy use. A more detailed analysis is required.

The composition of Chinese energy use (Fig.1, 2 and Table 5) is remarkable. In 1980, final energy consumption was dominated by coal and combustible wastes (over 80%). Combustible waste materials, which go entirely into the residential sector, declined steadily as a share of total consumption until the mid-1990s and have remained fairly steady since then.[9] Coal, on the other hand, showed some increase until the mid-1990s but has declined sharply since then. These fuels, which represent the "old" Chinese economy, today still account for approximately 56% of total final energy use. The decline in these fuels has been offset by rapid increase in the use of electricity and petroleum products that accounted respectively for 13 and 24% of total consumption in 2002.

On a per capita basis, energy consumption in China remains modest in comparison to other East Asian developing countries and/or in comparison with the advanced countries (Table 2, Fig. 5). On the other hand, energy inputs per unit of GDP (PPP basis) are close to the world average; even a little higher than in the advanced countries. This is consistent with the fact that energy use, particularly of coal, is not

[9] Many projections of Chinese energy consumption understate use by ignoring the consumption of combustible waste.

efficient by advanced country standards(Sinton, Levine, & Qingyi, 1998). Given China's large size, energy consumption in China represents a significant (12%) and rapidly increasing fraction of the world total.

The import requirements of the Chinese economy are of particular importance from a world perspective. Since the mid-1990s, China has changed from a moderate net exporter of coal to significant reliance on imported crude oil and petroleum products. Recently, net imports of crude oil account for 28% of total Chinese crude petroleum use and imports of petroleum products represent an additional 8% of petroleum products consumption. Perhaps more important is the rapid increase of Chinese petroleum imports at 15 to 20% annually. While Chinese imports of crude oil only accounted for 3.5% of total world crude oil trade, their growth represents a much larger fraction of the expansion of total world supply.

3.3.2 Energy Policy in China

In terms of policy in China, Five-Year Plan is the most important government document of China. It is a series of economic development initiatives, mapping strategies for economic development, setting growth targets and launching reforms in the relative time frame (Shiu & Lam, 2004). Since the establishment of People's Republic of China, the

Central Government has established 12 Five-Year Plans (Table 4). Every Five-Year Plan has its unique characteristics due to the specific period when it is composed and approved. The contents and major targets in the Five-Year Plans are changed significantly according to the economic development and social growth conditions. Each Five-Year Plan contains either a section or chapter related to national energy policy. For instance, the energy policies should promote the social acceptance or public awareness of renewable energy such as solar power (Yuan, Zuo, & Ma, 2011). In particular, as part of the national energy strategy framework, Five-Year Plans play a critical role to improve the structure of power generation (Zhao, Zuo, Fan, & Zillante, 2011).

Table 4 Five-Year Plans and the corresponding time frame

Five-Year	Time	Five-Year	Time	Five-Year	Time
1st	1953---1957	5th	1976---1980	9th	1996---2000
2nd	1958---1962	6th	1981---1985	10th	2001---2005
3rd	1966---1970	7th	1986---1990	11th	2006---2010
4th	1971---1975	8th	1991---1995	12th	2011---2015

The past 58 years (1953-2010) have witnessed that China’s energy policy has changed significantly by analyzing the 12 Five- Year Plans:

First, there are specific goals of coal production from the First Five-Year Plan to the Tenth Five-Year Plan and the specific goals of total energy production from the Sixth Five-Year Plan to the Ninth Five-Year Plan with the objectives of resolving issues associated with shortfall of energy supply. These goals have been achieved in all Five-Year Plans except the Tenth Five-Year Plan. This is due to the fact that all economies suffered from the Asian Financial Crisis during that period. In 1985, the end of the Sixth Five-Year Plan period, the actual production of total energy and coal reached 125% of the planned amount. This advanced energy development on one hand promoted and supported the rapid social and economy development to a large extent; on the other hand this brought negative impacts from energy conservation and environmental protection perspectives. This issue has been improved. The specific goal of energy production is not set since the Tenth Five-Year Plan, which indicates that the government will no longer simply encourage the enlargement of scale of energy production. Second, Transition from energy exporting to energy importing strategy. Due to the rapid economy development, the energy demand has increased dramatically in China. As a result, the Chinese government's energy strategy changed from encouraging exporting to increasing importing. As specified in the Seventh Five-Year Plan, China continuously devotes to increase exporting of petroleum, coal, nonferrous metals, grain and cotton''(State Council, 1986)[10]. However,

[10] Available at /http://ghs.ndrc.gov.cn/ghwb/gjwngh/>

the domestic production of crude oil could not satisfy the local requirements during the period of the Eighth Five-Year Plan. Consequently, China has become a net oil importer in 1993(see Fig.8). During the Tenth Five-Year Plan period, priorities were given to “reinforce oceanic exploration, explore overseas energy resources, establish overseas petroleum and natural gas supply base and diversify oil supplies” as a critical component of energy strategy(State Council,2001). The Tenth Five-Year Plan also saw the statement of “Construction of strategic petroleum reserve system in order to enhance the national energy security” for the very first time in the Five-Year Plans. This was described as “expanding the existing and establish new national petroleum reserve bases” in the Eleventh Five-Year Plan. It is reinforced in the Twelfth Five-Year Plan, which specified that “China will plan and construct energy reserve infrastructure properly; improve oil reserve system; strengthen natural gas and coal reserve and develop the emergency response system” (State Council, 2001, 2006, 2011). It has become the critical component of China’s energy policy to establish and expand the national petroleum reserves with the aim of enhancing the national energy security.

Third, more focus on energy efficiency, and new, renewable energy. The energy section of the First to the Fifth Five-Year Plans simply set up the goal of energy production at the end of that five- year period

(State Council, 1953, 1958, 1966, 1971, 1976). Since the Sixth Five-Year Plan, contents relating to controlling the energy consumption per unit of product have been raised. The Sixth Five-Year Plan specified that “in 1985 the energy consumption per unit of product will decrease 2.6-3.5% per year after various energy conservation measures are implemented. The energy consumption per unit of production of 17 major industrial products such as steel and electricity will decrease 3-12% within 5 years” (State Council, 1981). The Seventh Five-Year Plan specified that “the energy consumption per 1000 RMB of national income will be cut from 1.29 TCE in 1985 to 1.14 TCE”. The Eighth Five-Year Plan defined the target of cutting the energy consumption per 1000 RMB of GDP from 0.93 to 0.85 TCE at the end of that period with an annual energy conservation rate of 2.2% (State Council,1991). In terms of comprehensive energy consumption per ton of steel, it was planned to be cut from 1.63 to 1.55 TCE in the Eighth Five-Year Plan where the Ninth Five-Year Plan aims to further cut it down to below 1.45 TCE (State Council, 1991, 1996). The Eleventh Five-Year Plan set up an ambitious goal of improving the energy efficiency with the largest amplitude compared to other Five-Year Plans. It clearly specified that the energy consumption per unit of GDP will decrease around 20% (State Council, 2006). The recent released Twelfth Five-Year Plan set up a target that the energy consumption per unit of

GDP will decrease 16% in the next five years (State Council, 2011). These metrics indicate that the attitude of Chinese government changing from encouraging energy production to encouraging

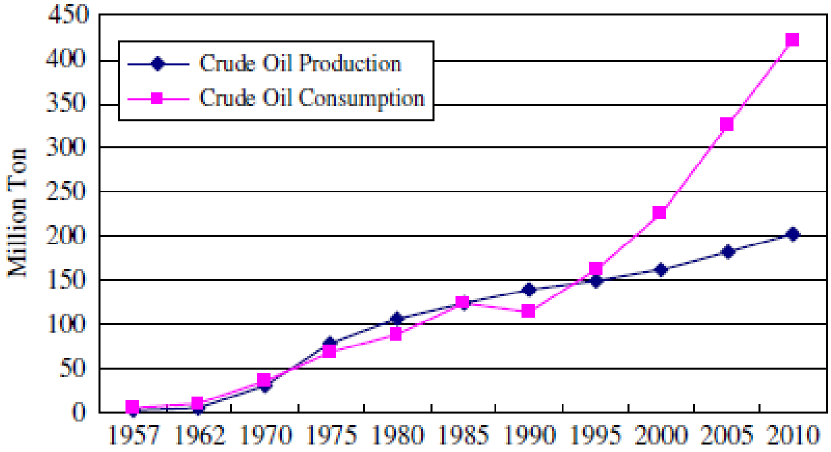

Fig. 8. Comparison of oil production and consumption in China

the energy efficiency improvement.

The development of new and renewable energy has gained increasing attention in the Five-Year Plans. The proportion of the new and renewable energy to total energy has increased from 3% in 1957 to about 11% in 2010 (see Fig. 9). There are descriptions similar to “proactive developing solar energy, wind energy and geothermal energy” since the Sixth Five-Year Plan. Year 2001 saw the Five-Year Plan dedicated to new and renewable energy for the very first time. The Tenth Five-Year Plan for New and Renewable Energy Commercialization Development has clearly specified that the annual utilization of new and renewable energy (excluding small hydro and biomass) will reach 13 million TCE by 2005 (National Economic and Trade Commission, 2001). China announced the Eleventh Five-Year Development Plan for New Energy and Renewable Energy in 2008. It clearly specified that the annual utilization of renewable energy will reach 300 million TCE. The installation capacity of hydro power, biomass power, wind power, solar hot water system and solar PV will reach 190 million KW, 5.5million KW, 10 million KW, 150 millionm2 and 300MW, respectively, by year 2010 (National Development and Reform Commission, 2008). In fact, all these goals have been achieved in 2009. Nuclear power showed in the Eighth Five-Year Plan for the first time, which encouraged the R&D on “200 MW nuclear heating reactor technologies’’. During the Eighth Five-Year Plan period (December 1991), Qinshan Nuclear Power Plant (300 MW), the first nuclear power plant in China was connected to the grid for electricity generation. Since then, nuclear power has drawn increasingly level of attention from the Chinese government. The Eleventh Five-Year Plan clearly stated that ‘‘China will proactively promote the nuclear power development with a priority on construction of million KW scale nuclear power stations’’. The Medium and Long-term Development Plan for Nuclear Energy was proposed in 2007, which specified the target of nuclear power development as ‘‘the installation capacity will reach 40 million KW and the annual electricity generation will reach 260–280 billion KWh by 2020’’ (National Development and Reform Commission, 2007). The incident of nuclear power station in Japan has trigged the intensive public scrutiny, which is reflected in the national policy on nuclear power development. The Twelfth Five-Year Plan stated that ‘‘China will develop nuclear power efficiently on the basis of security’’. The security has become the premise condition of the new era of nuclear power development in China. According to the Twelfth Five-Year Plan, the non-fossil fuel will account for 11.4% of total primary energy consumption by 2015 (State Council, 2011). Renewable energy resources will account for 20% of total energy consumption by 2020 (National Development and Reform Commission, 2007). The proportion of new energy and renewable energy to the energy mix will increase constantly in China.

Fourth, Concerning on air pollutant emission reduction, CO_2 emission and climate change. There are no contents related to the control of pollutant emission in the Five-Year Plans until the Tenth Five-Year Plan. Since the Eleventh Five-Year Plan, a specific target of controlling the sulfur dioxide (SO_2) emission is defined. According to the Eleventh Five-Year Plan, the total amount of SO_2 emission will decrease 10% by the end of year 2010 (State Council, 2006). This target, as the binding target, has to be achieved. According to the latest statistics of the Environmental Protection Authority, the SO_2 emission has been cut 14% at the end of the Eleventh Five-Year Plan compared to year 2005 level, exceeding even the expectation of 10% (National Bureau of Statistics of China, 2011). In the Twelfth Five-Year Plan, a target is defined that the SO_2 emission will be cut further 8% (State Council, 2011). Defining specific target of controlling the total amount of pollutant emission shows the increasingly level of attention of the Chinese government to environmental protection and sustain-

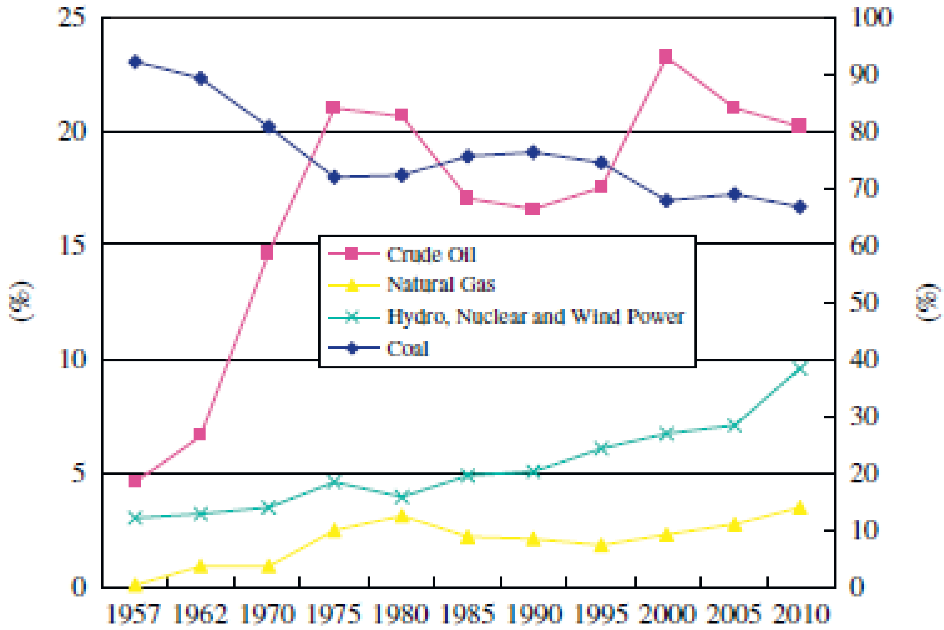

Fig. 9. Share of energy consumption by different energy types in China

-able development.

Contents related to greenhouse gas emission debuted in the Eleventh Five-Year Plan, which specified that ‘‘the greenhouse gas emission will be controlled effectively’’ (State Council, 2006). This indicates that the Chinese government starts concerning the climate change issues. However, the Eleventh Five-Year Plan provided only a general statement on controlling climate change, without specifying the actual targets. The climate change has received unprecedented attention in the Twelfth Five-Year Plan, which has a dedicated chapter discussing this issue. During the Twelfth Five-Year period, China will comprehensively utilize various measures such as adjusting industrial and energy structure, energy conservation and energy efficiency, increasing forest carbon sinks in order to reduce the energy consumption intensity and carbon dioxide emission intensity to a large extent. As a result, greenhouse gas emission can be controlled effectively. Other actions to be taken are as follows: (1) accelerate the R&D and implementation of low carbon technologies to control the greenhouse gas emission in major sectors such as industrial, building and construction, transport and agriculture; (2) establish standards, labeling system and accreditation system for low carbon products; (3) establish and improve the statistical and auditing system for greenhouse gas emission and (4) establish carbon trade market.

The specific targets specified in the Twelfth Five-Year Plan are as follows: (1) the CO2 emission per unit of GDP reduces 17%, (2) forest coverage increases to 21.66% and (3) forest volume increases 600 million cubic meters (State Council, 2011). It is a steady improvement made by the Twelfth Five-Year Plan to raise the specific control targets and implementation measures for carbon emission. This highlighted the commitments of the Chinese government to greenhouse gas emission reduction and climate change.

In summary, before 1980, the energy policy major targets are to expand energy production and consumption. The actual energy production increased more than 32 times from the First Five-Year Plan to the Eleventh Five-Year Plan. As the domestic energy consumption kept soaring, China started importing energy rather than exporting in the period of the Eighth Five-Year Plan. National petroleum reserve strategy has been formed since the Tenth Five-Year Plan (2001). Since the Sixth Five-Year Plan (1981), Chinese government has put more efforts on improving the energy efficiency. In order to meet the energy demand and reduce carbon dioxide emissions, new energy and renewable energy are receiving more attention in the Five-Year Plans. Furthermore, the energy policy of China is getting focused on global issues, such as carbon dioxide reduction and climate change.

Chapter 4 Methodology and Data

According to Engle and Granger (Engle & Granger, 1987), a linear combination of two or more non-stationary series (with the same order of integration) may be stationary. If such a stationary linear combination exists, the series are considered to be co-integrated and long run equilibrium relationships exist. Incorporating these co-integrated properties, an error-correction model (ECM) could be constructed to test for Granger causation of the series in at least one direction. In this paper, the VECM is specifically adopted to examine the Granger causality between real GDP and energy consumption in China.

Moreover, as a complementary method, we applied for energy consumption intensity and elasticity and decoupling index indicators.

4.1 Methodology Theoretical Background

In this paper, the energy consumption-economic growth relation analysis, which is based on timing sequence dimensions, needs to be examined using econometrics strictly and carefully. Consideration of data properties is necessary because appropriate methods depend on whether data is stationary for time series. If there is no co-integration in a posited regression among non-stationary variables, the regression could be spurious, and interpreting the results in the classical way would be invalid. Therefore, after individual unit root tests, using the co-integration tests and vector error correction model, find out investigate the relationship between energy consumption and economic growth. Furthermore, investigate the causal relationship between GDP and the disaggregate categories of energy consumption, including coal, oil, natural gas, and electricity.

4.1.1 Integration, Stationarity and Co-integration

Granger(Granger, 1981) points out that those time series only become stationary after differencing may have linear combinations. In that situation, those variables are said to be co-integrated. Pertaining to our models, if two variables are co-integrated, they are stationary of the same order and there is an equilibrium relationship between the two variables. Also, a linear combination of the two series produces residuals that are stationary. Therefore, it is essential to first test the series for stationarity and co-integration. A series is said to be non-stationary (or stationary) if it has non-constant (or constant) mean, variance, and auto-covariance (at various lags) over time. If a non-stationary series has to be differenced d times to become stationary, then it is said to be integrated of order d: i.e. I(d).

The augmented Dickey–Fuller (ADF) (Dickey & Fuller, 1979; Said & Dickey, 1984) and Phillips–Perron (PP)(Phillips & Perron, 1988) tests have been applied for examining unit roots and stationarity in this paper. For both tests, we are testing the null hypothesis H_0 , that Yt is non-stationary, against H1, that Yt is stationary.

When both series are integrated of the same order, we can proceed to test for the presence of co-integration. The Johansen maximum likelihood procedure (Johansen, 1988; Johansen & Juselius, 1990) is used for this purpose. Any long-run co-integrating relationship found between the series will contribute an additional error–correction term to the ECM.

4.1.2 Vector Error-correction Model

The existence of co-integration relationships indicates that there are long-run relationships among the variables, and thereby Granger causality among them in at least one direction. The ECM was introduced by Sargan (Sargan, 1964), and later popularized by Engle and Granger (Engle & Granger, 1987). It is used for correcting disequilibrium and testing for long and short-run causality among co-integrated variables. The error-correction equation to test for long-run causality when the two variables are co-integrated and the variables are stationary only after differencing is formulated as follows:

$$\Delta \mathrm{Y_t} = \partial_2 + \partial_{\mathrm{y}} \mu_{\mathrm{t-1}} + \sum_{i=1} \partial_{21}(i) \Delta \mathrm{Y}_{\mathrm{t}-i} + \sum_{i=1} \partial_{22}\,(i) \Delta \mathrm{X}_{\mathrm{t}-i} + \varepsilon_{\mathrm{yt}} \quad (1)$$

$$\Delta X_t = \partial_1 + \partial_x \mu_{t-1} + \sum_{i=1} \partial_{11}(i)\Delta Y_{t-i} + \sum_{i=1} \partial_{12}(i)\Delta X_{t-i} + \varepsilon_{xt} \quad (2)$$

Where Yt and Xt represent natural logarithms of real GDP and energy consumption, respectively, and (ΔY_t, ΔX_t) are the differences in these variables that capture their short-run disturbances. ε_{yt} , ε_{xt} are the serially uncorrelated error terms, and μ_{t-1} is the error-correction term (ECT), which is derived from the long-run co-integration relationship i.e. $Yt = \beta_0 + \beta_1 Xt + \mu_t$ and measures the magnitude of the past disequilibrium (it is called the ECT since the deviation from long-run equilibrium is corrected gradually through a series of partial short-run adjustments).

In each equation, change in the endogenous variable is caused not only by their lags, but also by the previous period's disequilibrium in level, i.e. μ_{t-1} . Given such a specification, the presence of short and long-run causality could be tested. Consider Eq. (1), if the estimated coefficients on lagged values of energy consumption are statistically significant, and then the implication is that the energy consumption Granger causes real GDP in the short-run. On the other hand, long-run causality can be found by testing the significance of the past disequilibrium term.

4.2 Hypotheses Development

In summarizing the theories from different background, we can say that the results depend on the different tests and models. Moreover, energy consumption intensity and decoupling index indicators led to many complementary analyses. Discussion of these situations led us to five hypotheses:

H1. GDP and aggregate energy consumption are supposed to be co-integrated and two-way causality, but weak decoupling trend.

H2. GDP and coal are supposed to be co-integrated and two-way causality.

H3. GDP and oil are supposed to be co-integrated ad at least one-way causality, but still coupling.

H4. GDP and gas are supposed to be co-integrated and at least one-way causality, but still coupling.

H5. GDP and electricity are supposed to be co-integrated and at least one-way causality, but still coupling.

4.3 Data and Variables

The empirical study uses the time series data of real GDP and energy consumption for the 1978-2011 from the World Bank Development Indicators, China statistical Yearbooks, China energy bureau (see table

5). GDP data is constant 2000 USD and the energy consumption series are expressed in terms of kiloliters of oil equivalent.

We distinguished all data into two levels: first, energy consumption quantity, apply for VECM to test causality. There are six variables, GDP, real gross domestic product; ENERGY, total energy consumption; COAL, coal consumption; OIL, oil consumption; GAS, natural gas consumption; ELEC, electricity consumption. The five explanatory variables are EC, COAL, OIL, GAS, ELEC; second, energy consumption intensity, elasticity and decoupling index.

It is evident from Figure 6 that the levels of GDP and energy consumption have significantly increased over time. We can see the similar variation tendency GDP and energy consumption, and both of them show the non-stationary properties. GDP in China and energy consumption appear closely related. Although average growth rates in the two variables will differ. We therefore expect the series of GDP to be co-integrated with the series of energy consumption in China.

Table 5 GDP and energy consumption and its composition(1978-2011)

Year	GDP **(constant 2000USD)**	EC **(Kt of oil equivalent)**	As percentage of total energy consumption (%)			ELEC **(KWh)**
			COAL	OIL	GAS	
1978	1.58E+11	5.91E+05	72.3	22.2	3.9	2.36e+11
1979	1.70E+11	6.00E+05	73.1	21.7	3.5	2.59e+11
1980	1.83E+11	5.98E+05	74.2	21.4	3.2	2.76E+11
1981	1.92E+11	5.94E+05	75.1	20.6	2.9	2.84E+11
1982	2.10E+11	6.13E+05	76.3	19.6	2.6	3.02E+11
1983	2.33E+11	6.37E+05	77.0	18.8	2.5	3.24E+11
1984	2.68E+11	6.76E+05	77.8	18.1	2.5	3.49E+11
1985	3.04E+11	6.92E+05	78.5	17.7	2.3	3.71E+11
1986	3.31E+11	7.17E+05	78.2	17.9	2.4	4.07E+11
1987	3.70E+11	7.53E+05	78.7	17.6	2.2	4.50E+11
1988	4.11E+11	7.94E+05	78.8	17.6	2.1	4.94E+11
1989	4.28E+11	8.11E+05	79.3	17.1	2.0	5.28E+11
1990	4.45E+11	8.63E+05	79.0	17.2	2.1	5.80E+11
1991	4.86E+11	8.57E+05	78.7	17.7	2.1	6.32E+11
1992	5.54E+11	8.86E+05	78.3	18.1	2.0	7.04E+11
1993	6.32E+11	9.37E+05	79.0	17.1	2.1	7.81E+11
1994	7.15E+11	9.80E+05	79.5	16.2	2.2	8.66E+11
1995	7.93E+11	1.05E+06	77.0	18.6	1.9	9.28E+11
1996	8.72E+11	1.08E+06	76.7	19.5	1.9	1.00E+12
1997	9.53E+11	1.09E+06	74.9	21.3	1.8	1.05E+12
1998	1.03E+12	1.09E+06	74.2	21.8	1.9	1.08E+12
1999	1.11E+12	1.09E+06	73.6	22.3	2.1	1.14E+12
2000	1.20E+12	1.09E+06	72.4	23.1	2.3	1.25E+12
2001	1.30E+12	1.09E+06	71.9	23.0	2.6	1.36E+12
2002	1.42E+12	1.18E+06	71.5	23.4	2.6	1.52E+12
2003	1.56E+12	1.35E+06	73.1	22.1	2.6	1.78E+12
2004	1.71E+12	1.57E+06	72.8	22.2	2.6	2.06E+12
2005	1.91E+12	1.70E+06	74.1	20.6	2.8	2.32E+12
2006	2.15E+12	1.85E+06	74.3	20.2	3.0	2.68E+12

(continued)

2007	2.46E+12	1.96E+06	74.3	19.7	3.5	3.07E+12
2008	2.69E+12	2.12E+06	74.9	19.2	2.9	3.25E+12
2009	2.94E+12	2.26E+06	74.0	18.8	4.1	3.50E+12
2010	3.25E+12	2.32E+06	71.9	20.0	4.6	4.19E+12
2011	3.55E+12	2.62E+06	73.5	21.3	5.7	4.69E+12

Note: GDP, EC, ELEC from World Bank database, Coal, Oil, Gas from China Statistical Yearbooks, various years.

Chapter 5 Empirical Analyses

The energy use is considered as an essential factor of production in the economic activities and economic growth is driven by increasing energy demands. In this section, we use the model to investigate the relationship between energy consumption and economic growth. The econometric methods used and the resulting empirical findings will be introduced in this section. Our empirical estimation has two objectives. The first is to examine how the variables are related in the long run. The second is to examine the dynamic causal relationships between the variables. The testing procedure involves three steps. We begin by performing an integration analysis using two unit root tests — augmented Dickey–Fuller (ADF) test, Phillips–Perron (PP) test. The second step is to test for co-integration using the Johansen's(Johansen, 1988) approach. Finally, the VECM estimators are used to evaluate the causality relationship among the variables considered.

5.1Unit Root Test

Before conducting the co-integration analysis of the time series data, we conduct a time series unit root test. We adopt two different unit root test methods---using the ADF and PP statistics. Table 6 and 7 shows the unit root test results for the series of all variables, including GDP, EC, COAL, OIL, GAS, and ELEC. As shown, the ADF and PP test values of all the variables are less than the critical value at the 5% level. This indicates that the series of all the variables are non-stationary. However, non-stationarity can be rejected for the series of all the variables at the 5% level when second-differenced data are used.[11] These indicate that the integration of real GDP and energy consumption for China is of order two, i.e. I(2). Hence, the co-integration models are estimated with un-differenced data, and the vector error-correction models with second-differenced data.

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[11] Null hypothesis H_0 equal to 1 was tested, that is, assume that there exists unit root. The result was compared with the critical value.

Table 6 Time series unit root test results (ADF)

Variables / Sequence	GDP	EC	COAL	OIL	GAS	ELEC
Origial	2762	3.007	2.574	1.883	3.919	3.687
Prob.	1.0000	1.0000	0.9939	0.9985	1.0000	1.0000
5%Critical values	-2.980	-2.980	-2.980	-2.980	-2.986	-2.989
D2	--5.417*	-5.949*	-5.135*	-11.742*	-11.641*	-6.702*
Prob.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5%Critical values	-2.983	-2.983	-2.983	-2.980	-2.983	-2.983

Note: D2 denotes second difference. Respectively, ADF represent the Augmented Dickey-Fuller unit root test and PP represent the Phillips-Perron unit root test, which examine the null hypothesis of non-stationarity, and * indicates statistical significance at the 5% critical value. Each ADF statistic is reported for the shortest lag length which has been chosen based on the minimum AIC.

Table 7 Time series unit root test results (PP)

Variables / Sequence	GDP	EC	COAL	OIL	GAS	ELEC
Origial	3.396	3.417	3.114	2.271	6.684	4.406
Prob.	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5%Critical values	-12.756					
D2.	-27.734*	-42.965*	-34.929*	-49.036*	-44.755*	-31.848*
Prob.	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
5%Critical values	-12.692					

Note: D2 denotes second difference.* indicates statistical significance at the 5% critical value.

The Phillips–Perron test uses the same models as the Dickey–Fuller tests, but uses a non-parametric correction, due to Newey and West (Newey & West, 1987), to address the potential serial correlation. We chose the lag truncation for this non-parametric correction using an automated bandwidth estimator employing the Bartlett kernel(Andrews, 1991). The test statistics for both the Dickey–Fuller and Phillips–Perron tests have the same distributions. Critical levels are reproduced in Hamilton (Hamilton, 1994) and Enders(Enders, 1995).

5.2 Co-integration Test

As stated previously, if GDP and energy consumption are non-stationary and the linear combination of the series of two variables is non-stationary, then standard Granger's causality test should be adopted. But, if GDP and energy consumption are non-stationary and the linear combination of the series of two variables is stationary, then error-correction modeling should be adopted. Therefore it is necessary to test for the co-integration property of the series of GDP and energy consumption before performing the causality test. Accordingly, we proceed to test GDP and energy consumption respectively, for co-integration in the data using the time series co-integration test developed by Johansen.

Given that integration of the series is of the same order from Table 6 and 7 we continued to test whether the series are co-integrated over the sample period. Our objective here is to test the variables for co-integration to determine whether there is a long-run relationship to control for in the econometric specification. Table 8 presents the Johansen co-integration test results. As shown in Table 8, the trace statistics mostly strongly reject the null hypothesis of no co-integration and fail to reject the null hypothesis of at most one co-integrating equation between GDP and EC, GDP and COAL, GDP and OIL, GDP and ELEC. This reveals that the GDP and EC, COAL, OIL, ELEC are co-integrated. However, between GDP and GAS, there is no evidence to show there is co-integrated relationship. Therefore, the results reject hypotheses 4. Respectively, it can be predicted that energy consumption (including coal, oil and electricity) and GDP variables move together in the long-run. Therefore, the standard Vector Error-Correction Model is applicable among these variables.

Table 8 Co-integration test results

Co-integration regression	rank	Trace statistic	5%critical value
LGDP—LEC	1	1.1116*	3.76
LGDP—LCOAL	1	2.1908*	3.76
LGDP—LOIL	1	1.3761*	3.76
LGDP—LGAS	0	8.2442	3.76
LGDP—LELEC	1	0.7035*	3.76

Note: * Shows significantly accept the null of one co-integration equation at the 5% level.

Before co-integration test, apply for the VARSOC(selection-order criteria) to determine the lags: GDP—EC(4lags), GDP—COAL(4lags), GDP—OIL(1lags), GDP—GAS(3lags), GDP—ELEC(4lags)

5.3 Vector Error-Correction Model and Causality Test

Co-integration implies the existence of causality, at least in one direction. However, it does not indicate the direction of the causal relationship. Hence, to shed light on the direction of causality, we perform the VECM causality tests. According to Engle and Granger (Engle & Granger, 1987), if two variables are co-integrated, then a more comprehensive test of causality, which has become known as an error-correction model, should be adopted to test if there is equilibrium in a short term between GDP and EC, COAL, OIL, ELEC. In this procedure, X Granger cause Y, if either the estimated coefficients on lagged values of X or the estimated coefficient on lagged value of error term from co-integrated regression is statistically significant. Similarly, Y Granger-cause X, if either the estimated coefficients on lagged values of Y or the estimated coefficient on lagged value of error term from co-integrated regression is statistically significant. The inclusion of lagged value of error term from co-integrated regression in the error-correction model gives an extra avenue through which the effects of causality can occur. Therefore it is necessary to test for the co-integration property of the energy consumption and GDP. Accordingly, a VECM is formulated to reintroduce the information lost in the differencing process, thereby allowing for long-run equilibrium as well as short-run dynamics.

Following the detection of the co-integrating relationship between GDP and EC, COAL, OIL, ELEC, a VECM was set up for investigating short and long-run causality. Various lag lengths were tried and the lag structures were chosen by varsoc selection-order criterion. Based on VECM, we apply for the causality test. The results of test between GDP and both the aggregate and the disaggregate categories of energy consumption are presented in Table 9-12. Table 9 reports VECM and causality test results between GDP and EC. Table 10-12 report VECM and causality test results between GDP and COAL, OIL, ELEC.

As shown in Table 9, it reveals that there is a two-way causality between GDP and EC both in the long run and short term, since they have had a significant econometrics impact on each other. Therefore, the results support hypotheses 1.

Table 10 reports VECM and causality test results between GDP and COAL. It reveals that there is a two-way causality between GDP and COAL both in the long run and short term, since for COAL in GDP equation and GDP in COAL equation are statistically significant. Therefore, the results support hypotheses 2.

Table 11 reports VECM and causality test results between GDP and OIL. It reveals that there is a one-way causality relationship from OIL to GDP in the long run. Conversely, in short term, for OIL in GDP equation and GDP in OIL equation are not statistically significant, implying that there is no causality relationship between oil consumption and GDP. Therefore, the results partly support hypotheses 3.

Table 12 reports VECM and causality test results between GDP and ELEC. It reveals that there is a two-way causality between GDP and ELEC both in the long run and short term, since they have had a significant econometrics impact on each other. For ELEC in GDP equation and GDP in ELEC equation are statistically significant, implying that there is bidirectional causality relationship between electricity consumption and GDP. Therefore, the results support hypotheses 5.

Table 9 The VECM and Granger causality test results between GDP and EC

Long-run causality	Short term causality					
GDP_t = -724269.1EC_t+3.85e+11	**EC⟶ GDP**			**GDP⟶ EC**		
EC⟶ GDP 0.11*(0.001)	ΔEC_{t-1}	ΔEC_{t-2}	ΔEC_{t-3}	ΔGDP_{t-1}	ΔGDP_{t-2}	ΔGDP_{t-3}
GDP⟶ EC 2.17e-07*(0.005)	283512.1* (0.001)	-43343.1 (0.717)	376899.8* (0.001)	9.59e-08 (0.840)	2.60e-07 (0.608)	-1.40e-06* (0.001)
Granger test	26.51* (0.0000)			13.85* (0.0031)		
lags	4					

Note: p-values are in the parentheses.

*denotes statistically significant.

Table 10 The VECM and Granger causality test results between GDP and COAL

Long-run causality	**Short term causality**					
GDP_t= -510827.3C_t+1.98e+11	**COAL⟶ GDP**			**GDP⟶ COAL**		
COAL⟶ GDP 0.01*(0.001)	ΔC_{t-1}	ΔC_{t-2}	ΔC_{t-3}	ΔGDP_{t-1}	ΔGDP_{t-2}	ΔGDP_{t-3}
GDP⟶ COAL 1.67e-07*(0.005)	330656.9* (0.010)	-6715.17 (0.971)	327219.6* (0.030)	2.46e-07 (0.582)	-1.07e-07 (0.832)	-1.43e-06* (0.002)
Granger test	19.74* (0.0002)			21.67* (0.0001)		
lags	4					

Note: p-values are in the parentheses.

*denotes statistically significant.

Table 11 The VECM and Granger causality test results between GDP and OIL

Long-run causality		**Short term causality**	
GDPt=(4.35e+07)O_t-(4.21e+12)		**OIL⟶ GDP**	**GDP⟶ OIL**
OIL⟶ GDP	0.01*(0.002)	ΔO_{t-1}	ΔGDP_{t-1}
GDP⟶ OIL	1.49e-09(0.346)	-109596.4(0.771)	6.79e-09(0.942)
Granger test		0.08(0.7709)	0.01(0.9416)
lags		**2**	

Note: p-values are in the parentheses.

*denotes statistically significant.

Table 12 The VECM and Granger causality test results between GDP and ELEC

Long-run causality	**Short term causality**					
GDP_t= -511308E_t+6.42e+10	**ELEC⟶GDP**			**GDP⟶ ELEC**		
ELEC⟶GDP 0.16*(0.000)	ΔE_{t-1}	ΔE_{t-2}	ΔE_{t-3}	ΔGDP_{t-1}	ΔGDP_{t-2}	ΔGDP_{t-3}
GDP⟶ELEC 4.37e-07*(0.000)	243459.6* (0.000)	-183531 (0.104)	714453.6* (0.000)	-1.38e-06* (0.008)	-9.69e-07 (0.155)	-6.45e-07 (0.336)
Granger test	49.09* (0.0000)			25.58* (0.0000)		
lags	4					

Note: p-values are in the parentheses.

*denotes statistically significant.

5.4 Discussion of the Empirical Results

This paper applies the VECM model to examine the causal relationship between aggregate energy consumption (including the disaggregate categories of energy consumption) and real GDP for China. Prior to testing for causality, the ADF, PP test and Johansen co-integration test were used to examine for unit roots and co-integration. And found: (1) there is a long run equilibrium relationship between GDP and aggregate energy consumption and the disaggregate categories of energy consumption except gas consumption; (2) a two-way causality runs between GDP and aggregate energy consumption, coal and electricity consumption as well; a one-way causality runs from oil consumption to GDP; (3) a significant decoupling trend of energy consumption and GDP growth; (4) preliminary evidence of structural change in terms of the disaggregate categories of energy consumption.

5. 4.1 Long Run Equilibrium

Evidence is found for the existence of a co-integrated relationship between GDP and energy consumption, coal, oil, electricity consumption in Table 8. There is an empirical long run relationship between GDP and energy consumption, coal, oil, electricity consumption. However, there is no co-integration relationship between

GDP and gas consumption. A possible explanation is that gas consumption has lightly portfolio in total energy consumption so that the gas consumption has no significant influence on the GDP growth, which supports the analyzing of energy consumption introduction part.

Accordingly, for energy consumption, the estimated co-integrating vector is log (real GDP) =2.04 +0.63 log (energy consumption) which indicates the long-run effect of energy on real GDP is 0.63. As for coal, the estimated co-integrating vector is log (real GDP) =0.52 +0.92 log(coal consumption) which indicates the long-run effect of coal on real GDP is 0.92. As for oil, the estimated co-integrating vector is log (real GDP) =2.91 +0.35 log (oil consumption) which indicates the long-run effect of oil on real GDP is 0.35. As for electricity, the estimated co-integrating vector is log (real GDP) =0.57 +0.90 log (electricity consumption) which indicates the long-run effect of energy on real GDP is 0.90.[12] Similar to other Asian economies, growth in China economy also depends on the expansion of the manufacturing sector. It explains the importance of energy consumption (especially coal and electricity) to real GDP in China since manufacturing is energy-intensive. Furthermore, Lam (Lam, 1999) documents that the real electricity prices by CLP and HEC are decreasing over time. Using an endogenous growth model, van Zon and Yetkiner (van Zon &

[12] For getting the elasticity coefficient, here apply for the natural logarithm variable.

Yetkiner, 2003) shows that when energy consumption is included as part of the input, the aggregate growth rate depends negatively on real energy prices. The drop in real energy prices increases the profitability of using new intermediate goods which have higher energy utilization rates and hence increases output. In equilibrium, the output is positively related to energy consumption.

5. 4.2 Causality and Dynamic Effect

Table 9-12 reports the causality tests based on the VECM. It shows that in both the short-run and the long-run there is two-way causality between GDP and energy consumption, GDP and coal consumption, GDP and electricity consumption. And there is only one-way causality from oil consumption to GDP in long-run. A two-way causality between GDP and energy consumption, coal, electricity consumption is a common empirical finding for many Asian economies. In searching for a possible explanation to this, it is helpful to note that energy use and economic growth complement each other. Energy consumption acts as a stimulus to economic growth and a high level of economic growth leads to a high level of energy use. The results also show that coal and electricity consumption plays an important role in economy development. China is a country heavily dependent on coal and electric energy.

What is different from many empirical findings is only one-way causality from oil consumption to GDP in long-run, and no significant causal relationship between GDP and oil consumption in short term. In searching for a possible explanation to this, note that the manufacturing sector growth plays an important role in their development. Due to the fiscal allocating funds and policy adjustment processes, Most of the time, the government invests in the infrastructure to alleviate the economic growth bottleneck and keep the stable GDP annual growth rate; the infrastructure generation usually dominates the growth of manufacturing sectors. The entire production sector increases the usage for the energy (such as electricity) demanding capital, hence shortages or instabilities in energy supply would lead to interruption of production; firms take this into the account when scheduling their production. It acts as a capacity constraint for the production process in the short run. The production process uses less than the full capacity of facilities allowed and utilizes labor and physical capital as a substitute in production. Therefore, the oil consumption has no significant influence on the GDP growth in short term.

As shown in Table 9-12, the one-period lag of energy consumption and coal consumption positively affects the GDP in the current period, whereas the three-period lag of GDP depresses contemporaneous energy consumption and coal consumption. The long run effect of energy on GDP is 63%, the coal on GDP is 92%. The negative sign in the GDP equation indicates that when the GDP is higher than the long-run equilibrium between real GDP and energy consumption (coal consumption as well), it cannot be sustained by the current usage level of energy (coal) and needs to adjust downward to the equilibrium level. On the other hand, when the difference between GDP and energy consumption (coal consumption as well) is positive, there is a need for more energy consumption (coal) in the long run and hence the energy consumption adjusts upward. The adjustment period is 3 years. Accordingly, the one-period lag of electricity consumption positively affects the GDP in the current period, whereas the one-period lag of GDP depresses contemporaneous electricity consumption. The long run effect of electricity on GDP is 90%, which imply that in China the electricity mainly comes from the coal. The negative sign in the GDP equation indicates that when the GDP is higher than the long-run equilibrium between real GDP and electricity consumption, it cannot be sustained by the current usage level of electricity and needs to adjust downward to the equilibrium level. On the other hand, when the difference between GDP and electricity is positive, there is a need for more electricity consumption in the long run and hence the electricity consumption adjusts upward. The adjustment period is 1 years.

5.4.3 Decoupling Trend

According to the OECD report (2002), the term “decoupling” means breaking the connection between environmental pressure and economic performance. In other words, the decoupling explores the relative growth rate of various environmental factors and economic driving force over a given period. The empirical results support there has been a relative decoupling trend of total energy consumption and GDP and a strong decoupling of oil consumption and GDP. The rate of growth of total energy consumption is not one to one direct correlation with GDP growth. The rapid growth in GDP might not trigger the similar growth in energy consumption. The decoupling of energy consumption and GDP growth can be a result of improvement in energy efficiency, and the oil reservation might be one of reasons for the decoupling of oil consumption and GDP. There is more and more evidence suggesting that the Chinese economy is more energy efficient today than a decade ago. Contrary to other developing countries, both the energy intensity and electricity intensity in China have been below unity over the last decade. In other words, one unit of electricity consumption can support more than one unit of GDP.

In terms of coal and electricity consumption, although the causality tests results imply there is still a bidirectional relationship with GDP, the sharp fall in coal and electricity energy intensity indicate the decoupling trend with GDP on some level. Two major reasons are proposed that they are improvement in electricity efficiency of electrical appliances and equipment, and conservation efforts to reduce electricity consumption. It is argued that electricity demand in China has shifted from quantitative to qualitative growth. Hence, it is not surprising to find that rapid GDP growth did not lead to corresponding growth in electricity and coal consumption.

This does not mean that energy consumption does not matter for the Chinese economy; however, the analysis shows that the role of energy consumption is relatively small. This has important policy consequences, as it suggests that energy restrictions do not seem to harm economic growth in China.

5.4.4 Structural Change

The finding of a uni-directional causality running from oil consumption to GDP in the long run implies that China is an oil-independent economy, in line with its economic policy to achieve oil independence in the long run. The results seem to suggest that the implementation of oil conservation policies has not inversely affected the long-term economic performance of China. Hence, the results imply that the economy of China may be less vulnerable to energy shocks, which could adversely affect GDP growth. However, Fig.2 shows that the coal consumption in China keeps slowly increasing, and the oil and gas keeps the sharply increasing (regardless the slight proportion). Electricity consumption illustrates a similar pattern. The change in the composition of electricity affects the relationship between GDP and electricity consumption. It shows a sharp decrease in the 1990s when manufacturing sectors was still dominating the electricity consumption of China due to improvements in efficiency. However, the slope of the decline flattened out in 2000 when the commercial sector took over manufacturing sector and become the largest electricity consumption sector. Finally, the ratio shows a slight increase in the 2010. The implication of the change in the economic structure on our results is shown; we find the coefficients are all significant except oil and gas consumption, which indicates that GDP reacts as much as implied by the long-run relationship in the last thirty years. If the decreasing trend persists into the future, the current relationship between GDP and total energy consumption, coal, electricity variables may be altered. Research on the possible change in the relationship among those variables deserves further investigation.

As shown in Fig.7, there is a higher elastic coefficient in the period of 1980-1996 and 2002-2007. This is because that in the first period China is in the early time of reform and opening up, so economic structural changed greatly and caused the higher sensitivity than any other period.

However, as China getting rid out of the Soviet economy, and establishing new economy system successfully, the economy began to appear overheated situation. Therefore, since 1996, China implemented macroeconomic control to achieve China’s economic "soft landing". However, since Asian financial crisis erupted in 1997 and international crude oil prices went up, Chinese government changed the economic structure and focus on infrastructure reconstruction in order to keep higher GDP. Therefore, the higher GDP resulted from the higher energy consumption. Especially with China's entry into WTO in 2001, this brought another round of high economic growth. Investment was growing rapidly, and energy-intensive products were also increased significantly, which made energy demand soaring and appeared energy use inefficiencies. During the Tenth Five-Year Plan Period, energy utilization efficiency of China is 32% and energy system efficiency is about 9.3%, which is equivalent to about 50% of developed countries’. More than 90% of the energy is lost and wasted in the course of mining, processing, storage and transportation and terminal utilization. Although, recent years the third industry such as low energy consumption industries and high value-added industries were developing gradually, so the sensitivity of energy consumption on economic growth was diminishing rapidly.

Chapter 6 Conclusions and Policy Implications

6.1 Conclusions

In examining the causal relationship between energy consumption and economic growth, instead of using one bivariate time series model, this paper constructed four bivariate models: GDP and aggregate energy consumption, GDP and coal consumption, GDP and oil consumption, GDP and electricity consumption model. To test Granger causality, this paper employed a VECM, instead of a VAR model, because we have found strong evidence that the variables are co-integrated.

The estimation and test results indicate: There is no evidence to show co-integrated relationship between gas consumption and GDP; In long run, there is two-way causality relationship between GDP and aggregate energy consumption and coal, electricity consumption and one-way causality from oil to GDP; In short term, Two-way causality runs between GDP and aggregate energy consumption, coal and electricity consumption as well. The adjustment period is 3 years between GDP and energy consumption and coal consumption, however, the adjustment period is 1 year between GDP and electricity consumption; and no causality between oil consumption and GDP.

Our empirical findings support the notion that Chinese economy is still based on both the energy intensity and electricity (mainly come from coal) intensity; however, there has been a decoupling trend of energy consumption and economic growth. The rate of growth of total energy consumption is not one to one direct correlation with GDP growth. The rapid growth in GDP might not trigger the similar growth in energy consumption. This direction of causation shed light on future energy policies regarding environmental protection, generation, transmission and distribution.

6.2 Policy Implications

From a policy point of view, the focus of current and future energy policies of China is placed on increasing energy efficiency, developing new energy and renewable energy, reducing carbon dioxide emissions and improving the capability of dealing with climate change. China is on transition to energy efficiency and low carbon for a sustainable development.

In detail, for aggregate energy consumption, it is important for the Chinese government to increase the fuel-tax and encourage renewable energy producing and consuming. For coal, transfer demand-satisfied policy into tightening consumption and total control policy, setting the fixed total consumption, and developing the clean coal technology; For oil, put forward tightening consumption and total control policy and establish strategic oil reserves system; For natural gas, significant state investment for the supplying natural gas terminals and pipes to solve the bottleneck, removing the price differentials to stimulate rural gas consumption increasing; For electricity, upgrade and speed up the rural distribution grids, control the total of coal electricity, emphasizing on exploiting hydropower wind power.

We find historic evidence from the Japanese economy, which shows that since the two Oil Shocks, economic growth may not have been held back even with a parsimonious energy policy. This experience may have made it possible for Japan to commit to very tight limitations on CO2 emissions under the Kyoto Protocol.

6.3 Limitations and Arguments

Since the decoupling is a relative new theory comparing with VECM, this paper only use the decoupling index as a complementary method to test whether GDP is decoupling from energy consumption in China. However, how to identify the relationship between VECM and decoupling index? Could we depend on only the VECM results to make the causality conclusion? Or could we make the coupling or decoupling trend according to the decoupling index given by OECD? What should be the rational explanations if both of VECM and decoupling index results are totally conflict? Ignoring any of the results in the statistical analysis can lead to incorrect estimates and mislead in policy recommendations. In terms of future research, the above questions should be taken into account.

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Appendix

Appendix 1 Lags index test:

. dfgls GDP

DF-GLS for GDP   Number of obs =   24

Maxlag = 9 chosen by Schwert criterion

[lags]	DF-GLS tau Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
9	-1.866	-3.770	-2.811	-2.388
8	-1.791	-3.770	-2.788	-2.406
7	-1.873	-3.770	-2.814	-2.460
6	-1.904	-3.770	-2.879	-2.542
5	-1.767	-3.770	-2.971	-2.643
4	-2.149	-3.770	-3.080	-2.754
3	-2.635	-3.770	-3.195	-2.866
2	-1.619	-3.770	-3.305	-2.970
1	-1.620	-3.770	-3.400	-3.058

Opt Lag (Ng-Perron seq t) = 0 [use maxlag(0)]

Min SC   =48.27271 at lag   1 with RMSE   2.66e+10

Min MAIC =48.37508 at lag   1 with RMSE   2.66e+10

. dfgls EC

DF-GLS for EC Number of obs = 24

Maxlag = 9 chosen by Schwert criterion

[lags]	DF-GLS tau Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
9	-2.189	-3.770	-2.811	-2.388
8	-2.180	-3.770	-2.788	-2.406
7	-1.658	-3.770	-2.814	-2.460
6	-0.917	-3.770	-2.879	-2.542
5	-1.088	-3.770	-2.971	-2.643
4	-0.588	-3.770	-3.080	-2.754
3	-0.694	-3.770	-3.195	-2.866
2	-0.676	-3.770	-3.305	-2.970
1	-0.029	-3.770	-3.400	-3.058

Opt Lag (Ng-Perron seq t) =7 with RMSE 48405.13

Min SC =22.40517 at lag 1 with RMSE 64226.15

Min MAIC =22.22375 at lag 1 with RMSE 64226.15

. dfgls Coal

DF-GLS for Coal Number of obs = 24

Maxlag = 9 chosen by Schwert criterion

[lags]	DF-GLS tau Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
9	-2.421	-3.770	-2.811	-2.388
8	-2.179	-3.770	-2.788	-2.406
7	-1.428	-3.770	-2.814	-2.460
6	-1.121	-3.770	-2.879	-2.542
5	-1.142	-3.770	-2.971	-2.643
4	-0.836	-3.770	-3.080	-2.754
3	-1.367	-3.770	-3.195	-2.866
2	-0.684	-3.770	-3.305	-2.970
1	-0.158	-3.770	-3.400	-3.058

Opt Lag (Ng-Perron seq t) =8 with RMSE 41368.89

Min SC =22.21605 at lag 1 with RMSE 58431.22

Min MAIC =22.03693 at lag 1 with RMSE 58431.22

. dfgls oil

DF-GLS for oil Number of obs = 24

Maxlag = 9 chosen by Schwert criterion

[lags]	DF-GLS tau Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
9	-1.898	-3.770	-2.811	-2.388

8	-2.015	-3.770	-2.788	-2.406
7	-1.596	-3.770	-2.814	-2.460
6	-0.925	-3.770	-2.879	-2.542
5	-0.734	-3.770	-2.971	-2.643
4	-0.537	-3.770	-3.080	-2.754
3	-0.403	-3.770	-3.195	-2.866
2	-0.615	-3.770	-3.305	-2.970
1	-0.202	-3.770	-3.400	-3.058

Opt Lag (Ng-Perron seq t) =7 with RMSE 10793.98

Min SC =19.32056 at lag 2 with RMSE 12857.12

Min MAIC =19.13247 at lag 2 with RMSE 12857.12

. dfgls Gas

DF-GLS for Gas Number of obs = 24

Maxlag = 9 chosen by Schwert criterion

[lags]	DF-GLS tau Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
9	-1.747	-3.770	-2.811	-2.388
8	-1.881	-3.770	-2.788	-2.406
7	-2.210	-3.770	-2.814	-2.460
6	-2.547	-3.770	-2.879	-2.542
5	-2.341	-3.770	-2.971	-2.643

4	-1.963	-3.770	-3.080	-2.754
3	-1.056	-3.770	-3.195	-2.866
2	-0.459	-3.770	-3.305	-2.970
1	0.190	-3.770	-3.400	-3.058

Opt Lag (Ng-Perron seq t) =4 with RMSE 4816.96

Min SC =17.62189 at lag 4 with RMSE 4816.96

Min MAIC =17.54055 at lag 3 with RMSE 5259.645

. dfgls ELEC

DF-GLS for ELEC Number of obs = 24

Maxlag = 9 chosen by Schwert criterion

[lags]	DF-GLS tau Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
9	-1.287	-3.770	-2.811	-2.388
8	-1.774	-3.770	-2.788	-2.406
7	-1.705	-3.770	-2.814	-2.460
6	-2.509	-3.770	-2.879	-2.542
5	-1.449	-3.770	-2.971	-2.643
4	-1.341	-3.770	-3.080	-2.754
3	-3.918	-3.770	-3.195	-2.866
2	-0.456	-3.770	-3.305	-2.970
1	-0.360	-3.770	-3.400	-3.058

Opt Lag (Ng-Perron seq t) =7 with RMSE 30584.38

Min SC =21.71584 at lag 7 with RMSE 30584.38

Min MAIC =22.15854 at lag 4 with RMSE 42328.83

Appendix 2 Unit roots tests:

2.1 ADF test

. dfuller GDP,lags(1)

Augmented Dickey-Fuller test for unit root Number of obs=32

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	2.762	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 1.0000

. dfuller d.GDP

Dickey-Fuller test for unit root Number of obs=32

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	0.635	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 0.9885

. dfuller d2.GDP

Dickey-Fuller test for unit root Number of obs=31

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
		---------- Interpolated Dickey-Fuller ---------		
Z(t)	-5.417	-3.709	-2.983	-2.623

MacKinnon approximate p-value for Z(t) = 0.0000

. dfuller EC,lags(1)

Augmented Dickey-Fuller test for unit root Number of obs=32

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
		---------- Interpolated Dickey-Fuller ---------		
Z(t)	3.007	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 1.0000

. dfuller d.EC

Dickey-Fuller test for unit root Number of obs=32

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-1.216	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 0.6668

. dfuller d2.EC

Dickey-Fuller test for unit root Number of obs=31

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-5.949	-3.709	-2.983	-2.623

MacKinnon approximate p-value for Z(t) = 0.0000

. dfuller Coal,lags(1)

Augmented Dickey-Fuller test for unit root Number of obs=32

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value

Z(t)	2.574	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 0.9991

. dfuller d.Coal

Dickey-Fuller test for unit root Number of obs=32

		---------- Interpolated Dickey-Fuller ---------		
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-1.925	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 0.3203

. dfuller d2.Coal

Dickey-Fuller test for unit root Number of obs=31

		---------- Interpolated Dickey-Fuller ---------		
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-5.135	-3.709	-2.983	-2.623

MacKinnon approximate p-value for Z(t) = 0.0000

. dfuller oil,lags(2)

Augmented Dickey-Fuller test for unit root   Number of   obs=31

		---------- Interpolated Dickey-Fuller ---------		
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	1.883	-3.709	-2.983	-2.623

MacKinnon approximate p-value for Z(t) = 0.9985

. dfuller d.oil

Dickey-Fuller test for unit root   Number of   obs=32

		---------- Interpolated Dickey-Fuller ---------		
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-4.299	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 0.0004

. dfuller d2.oil

Dickey-Fuller test for unit root Number of obs=31

	---------- Interpolated Dickey-Fuller ---------			
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-11.742	-3.709	-2.983	-2.623

MacKinnon approximate p-value for Z(t) = 0.0000

. dfuller Gas,lags(3)

Augmented Dickey-Fuller test for unit root Number of obs=30

	---------- Interpolated Dickey-Fuller ---------			
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	3.919	-3.716	-2.986	-2.624

MacKinnon approximate p-value for Z(t) = 1.0000

. dfuller d.Gas

Dickey-Fuller test for unit root Number of obs=32

---------- Interpolated Dickey-Fuller ---------

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-4.219	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 0.0006

. dfuller d2.Gas

Dickey-Fuller test for unit root Number of obs=31

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-11.641	-3.709	-2.983	-2.623

MacKinnon approximate p-value for Z(t) = 0.0000

. dfuller ELEC,lags(4)

Augmented Dickey-Fuller test for unit root Number of obs=29

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value

Z(t)	3.687	-3.723	-2.989	-2.625

MacKinnon approximate p-value for Z(t) = 1.0000

. dfuller d.ELEC

Dickey-Fuller test for unit root Number of obs=32

	---------- Interpolated Dickey-Fuller ---------			
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-1.098	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 0.7160

. dfuller d2.ELEC

Dickey-Fuller test for unit root Number of obs=31

	---------- Interpolated Dickey-Fuller ---------			
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-6.702	-3.709	-2.983	-2.623

MacKinnon approximate p-value for Z(t) = 0.0000

2.2 PP test

. pperron GDP,lags(1)

Phillips-Perron test for unit root Number of obs=33

Newey-West lags = 1

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	3.396	-17.744	-12.756	-10.360
Z(t)	18.071	-3.696	-2.978	-2.620

MacKinnon approximate p-value for Z(t) = 1.0000

. pperron d.GDP

Phillips-Perron test for unit root Number of obs=32

Newey-West lags = 3

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	1.422	-17.676	-12.724	-10.340
Z(t)	1.138	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 0.9955

. pperron d2.GDP

Phillips-Perron test for unit root Number of obs=31

Newey-West lags = 3

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	-27.734	-17.608	-12.692	-10.320
Z(t)	-5.441	-3.709	-2.983	-2.623

MacKinnon approximate p-value for Z(t) = 0.0000

. pperron EC,lags(1)

Phillips-Perron test for unit root Number of obs=33

Newey-West lags = 1

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	3.417	-17.744	-12.756	-10.360
Z(t)	5.257	-3.696	-2.978	-2.620

MacKinnon approximate p-value for Z(t) = 1.0000

. pperron d.EC

Phillips-Perron test for unit root Number of obs=32

Newey-West lags = 3

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	-4.402	-17.676	-12.724	-10.340
Z(t)	-0.867	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 0.7985

. pperron d2.EC

Phillips-Perron test for unit root Number of obs=31

Newey-West lags = 3

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	-42.965	-17.608	-12.692	-10.320

Z(t)	-5.861	-3.709	-2.983	-2.623

MacKinnon approximate p-value for Z(t) = 0.0000

. pperron Coal,lags(1)

Phillips-Perron test for unit root Number of obs=33

Newey-West lags = 1

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
		---------- Interpolated Dickey-Fuller ---------		
Z(rho)	3.114	-17.744	-12.756	-10.360
Z(t)	3.724	-3.696	-2.978	-2.620

MacKinnon approximate p-value for Z(t) = 1.0000

. pperron d.Coal

Phillips-Perron test for unit root Number of obs=32

Newey-West lags = 3

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
		---------- Interpolated Dickey-Fuller ---------		

Z(rho)	-10.739	-17.676	-12.724	-10.340
Z(t)	-1.771	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 0.3947

. pperron d2.Coal

Phillips-Perron test for unit root Number of obs=31

Newey-West lags = 3

		---------- Interpolated Dickey-Fuller ---------		
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	-34.929	-17.608	-12.692	-10.320
Z(t)	-4.632	-3.709	-2.983	-2.623

MacKinnon approximate p-value for Z(t) = 0.0001

. pperron oil,lags(2)

Phillips-Perron test for unit root Number of obs=33

Newey-West lags = 2

		---------- Interpolated Dickey-Fuller ---------		
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value

Z(rho)	2.271	-17.744	-12.756	-10.360
Z(t)	3.721	-3.696	-2.978	-2.620

MacKinnon approximate p-value for Z(t) = 1.0000

. pperron d.oil

Phillips-Perron test for unit root Number of obs=32

Newey-West lags = 3

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	-25.926	-17.676	-12.724	-10.340
Z(t)	-4.372	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 0.0003

. pperron d2.oil

Phillips-Perron test for unit root Number of obs=31

Newey-West lags = 3

---------- Interpolated Dickey-Fuller ---------

Test 1% Critical 5% Critical 10% Critical

	Statistic	Value	Value	Value
Z(rho)	-49.036	-17.608	-12.692	-10.320
Z(t)	-13.880	-3.709	-2.983	-2.623

MacKinnon approximate p-value for Z(t) = 0.0000

. pperron Gas,lags(3)

Phillips-Perron test for unit root Number of obs=33

Newey-West lags = 3

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	6.684	-17.744	-12.756	-10.360
Z(t)	7.745	-3.696	-2.978	-2.620

MacKinnon approximate p-value for Z(t) = 1.0000

. pperron d.Gas

Phillips-Perron test for unit root Number of obs=32

Newey-West lags = 3

---------- Interpolated Dickey-Fuller ---------

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	-28.174	-17.676	-12.724	-10.340
Z(t)	-4.389	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 0.0003

. pperron d2.Gas

Phillips-Perron test for unit root Number of obs=31

Newey-West lags = 3

	---------- Interpolated Dickey-Fuller ---------			
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	-44.755	-17.608	-12.692	-10.320
Z(t)	-18.721	-3.709	-2.983	-2.623

MacKinnon approximate p-value for Z(t) = 0.0000

. pperron ELEC,lags(4)

Phillips-Perron test for unit root Number of obs=33

Newey-West lags = 4

	---------- Interpolated Dickey-Fuller ---------			
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	4.406	-17.744	-12.756	-10.360
Z(t)	13.184	-3.696	-2.978	-2.620

MacKinnon approximate p-value for Z(t) = 1.0000

. pperron d.ELEC

Phillips-Perron test for unit root Number of obs=32

Newey-West lags = 3

	---------- Interpolated Dickey-Fuller ---------			
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	-1.549	-17.676	-12.724	-10.340
Z(t)	-0.487	-3.702	-2.980	-2.622

MacKinnon approximate p-value for Z(t) = 0.8945

. pperron d2.ELEC

Phillips-Perron test for unit root Number of obs=31

Newey-West lags = 3

	Test Statistic	---------- Interpolated Dickey-Fuller --------- 1% Critical Value	5% Critical Value	10% Critical Value
Z(rho)	-31.848	-17.608	-12.692	-10.320
Z(t)	-7.407	-3.709	-2.983	-2.623

MacKinnon approximate p-value for Z(t) = 0.0000

Appendix 3 Co-integration tests:

3.1 lags test:

varsoc GDP EC

Selection-order criteria

Sample: 1982 - 2011 Number of obs= 30

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-1246.59				4.8e+33	83.2392	83.2691	83.3326
1	-1121.34	250.49	4	0.000	1.5e+30	75.1561	75.2457	75.4363
2	-1112.25	18.185	4	0.001	1.1e+30	74.8165	74.966	75.2836*
3	-1107.15	10.186	4	0.037	1.0e+30	74.7437	74.9528	75.3975
4	-1100.33	13.655*	4	0.008	8.5e+29*	74.5551*	74.8241*	75.3959

Endogenous: GDP EC

Exogenous: _cons

. varsoc GDP Coal

Selection-order criteria

Sample: 1982 - 2011 Number of obs=30

+---

|lag | LL LR df p FPE AIC HQIC SBIC

|

```
|----+--------------------------------------------------------------------------------------------------
|    0 | -1245.76                                    4.6e+33     83.1839     83.2138     83.2773    |
|    1 | -1120.01    251.49       4    0.000    1.4e+30     75.0676     75.1573     75.3479    |
|    2 |    -1109.5      21.02       4    0.000    8.9e+29     74.6337     74.7831     75.1007    |
|    3 | -1103.23    12.551       4    0.014    7.8e+29       74.482     74.6912     75.1359    |
|    4 | -1094.39    17.681*     4    0.001    5.7e+29*   74.1593*   74.4282*            75* |
+-----------------------------------------------------------------------------------------------------
   Endogenous:    GDP Coal
     Exogenous:    _cons
```

. varsoc GDP oil

```
   Selection-order criteria
   Sample:    1982 - 2011                                        Number of    obs=30
+-----------------------------------------------------------------------------------------------------
|lag  |        LL           LR          df        p          FPE           AIC          HQIC          SBIC
|
|----+--------------------------------------------------------------------------------------------------
|    0 | -1204.86                                    3.0e+32       80.457     80.4869     80.5504    |
|    1 | -1080.03    249.65*     4    0.000    9.5e+28     72.4021     72.4918*    72.6824* |
|    2 | -1075.53    9.0064       4    0.061    9.3e+28*   72.3686*      72.518     72.8356    |
|    3 | -1072.54    5.9833       4    0.200    1.0e+29     72.4358       72.645     73.0897    |
|    4 | -1068.59    7.9031       4    0.095    1.0e+29       72.439       72.708     73.2797    |
+-----------------------------------------------------------------------------------------------------
   Endogenous:    GDP oil
     Exogenous:    _cons
```

. varsoc GDP Gas

Selection-order criteria

Sample: 1982 - 2011 Number of obs=30

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-1183.41				7.2e+31	79.0273	79.0572	79.1207
1	-1057.19	252.43	4	0.000	2.1e+28	70.8796	70.9692	71.1598
2	-1034.22	45.955	4	0.000	5.9e+27	69.6144	69.7639	70.0815
3	-1019.39	29.66*	4	0.000	2.9e+27*	68.8924*	69.1016*	69.5463*
4	-1016.37	6.0382	4	0.196	3.2e+27	68.9578	69.2268	69.7986

Endogenous: GDP Gas

Exogenous: _cons

. varsoc GDP ELEC

Selection-order criteria

Sample: 1982 - 2011 Number of obs=30

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-1262.26				1.4e+34	84.2842	84.3141	84.3776
1	-1133.14	258.24	4	0.000	3.3e+30	75.9427	76.0324	76.223

2	-1122.73	20.827	4	0.000	2.2e+30	75.5152	75.6646	75.9822
3	-1113.25	18.953	4	0.001	1.5e+30	75.1501	75.3592	75.8039
4	-1089.03	48.451*	4	0.000	4.0e+29*	73.8017*	74.0706*	74.6424*

Endogenous: GDP ELEC

Exogenous: _cons

. varsoc GDP Electric

Selection-order criteria

Sample: 1982 - 2011 Number of obs=30

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-1676.73				1.4e+46	111.915	111.945	112.009
1	-1547.61	258.24	4	0.000	3.3e+42	103.574	103.663	103.854
2	-1537.19	20.827	4	0.000	2.2e+42	103.146	103.296	103.613
3	-1530.77	12.836	4	0.012	1.9e+42	102.985	103.194	103.639
4	-1523.02	15.5*	4	0.004	1.5e+42*	102.735*	103.004*	103.576*

Endogenous: GDP Electric

Exogenous: _cons

3.2 rank test:

. vecrank GDP EC,lags(4)

Johansen tests for cointegration

Trend: constant Number of obs =30

Sample: 1982 - 2011 Lags = 4

----

maximum rank	parms	LL	eigenvalue	trace statistic	5% critical value
0	14	-1111.7747	.	22.8939	15.41
1	17	-1100.8836	0.51620	1.1116*	3.76
2	18	-1100.3278	0.03638		

. vecrank GDP Coal,lags(4)

Johansen tests for cointegration

Trend: constant Number of obs = 30

Sample: 1982 - 2011 Lags =4

----

maximum rank	parms	LL	eigenvalue	trace statistic	5% critical value
0	14	-1109.8817	.	30.9802	15.41
1	17	-1095.487	0.61697	2.1908*	3.76
2	18	-1094.3916	0.07043		

. vecrank GDP oil,lags(1)

Johansen tests for cointegration

Trend: constant Number of obs =33

Sample: 1979 - 2011 Lags = 1

maximum rank	parms	LL	eigenvalue	trace statistic	5% critical value
0	2	-1233.4172	.	95.1249	15.41
1	5	-1186.5429	0.94163	1.3761*	3.76
2	6	-1185.8548	0.04084		

. vecrank GDP Gas,lags(3)

Johansen tests for cointegration

Trend: constant Number of obs =31

Sample: 1981 - 2011 Lags = 3

maximum rank	parms	LL	eigenvalue	trace statistic	5% critical value
0	10	-1062.2907	.	18.5034	15.41
1	13	-1057.1611	0.28175	8.2442	3.76
2	14	-1053.039	0.23352		

. vecrank GDP ELEC,lags(4)

Johansen tests for cointegration

Trend: constant Number of obs =30

Sample: 1982 - 2011 Lags = 4

maximum rank	parms	LL	eigenvalue	trace statistic	5% critical value
0	14	-1104.7458	.	31.4379	15.41
1	17	-1089.3786	0.64102	0.7035*	3.76
2	18	-1089.0269	0.02318		

Appendix 4 VECM test

. vec GDP EC,lags(4)

Vector error-correction model

Sample: 1982 - 2011 No. of obs=30

AIC =74.52555

Log likelihood = -1100.883 HQIC =74.77956

Det(Sigma_ml) =2.56e+29 SBIC =75.31956

Equation	Parms	RMSE	R-sq	chi2	P>chi2
D_GDP	8	1.7e+10	0.9898	2130.64	0.0000
D_EC	8	41151.6	0.8741	152.6736	0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
D_GDP						
_ce1						
L1.	.1076571	.0319373	3.37	0.001	.0450612	.1702529
GDP						
LD.	.4562228	.1962511	2.32	0.020	.0715777	.8408679
L2D.	-.5788054	.2100022	-2.76	0.006	-.9904021	-.1672086
L3D.	.1924991	.1827602	1.05	0.292	-.1657044	.5507026

|						
EC |						
LD. |	283512.1	87961.68	3.22	0.001	111110.3	455913.8
L2D. |	-43343.05	119469.2	-0.36	0.717	-277498.4	190812.4
L3D. |	376899.8	109767.4	3.43	0.001	161759.6	592040
|						
_cons |	.0232221	5.21e+09	0.00	1.000	-1.02e+10	1.02e+10
D_EC |						
_ce1 |						
L1. |	2.17e-07	7.71e-08	2.82	0.005	6.60e-08	3.68e-07
|						
GDP |						
LD. |	9.59e-08	4.73e-07	0.20	0.840	-8.32e-07	1.02e-06
L2D. |	2.60e-07	5.07e-07	0.51	0.608	-7.33e-07	1.25e-06
L3D. |	-1.40e-06	4.41e-07	-3.18	0.001	-2.27e-06	-5.38e-07
|						
EC |						
LD. |	.2578427	.2122189	1.21	0.224	-.1580986	.6737841
L2D. |	.34861	.2882349	1.21	0.226	-.2163201	.91354
L3D. |	-.1948186	.264828	-0.74	0.462	-.713872	.3242348
|						
_cons |	-11773.45	12560.82	-0.94	0.349	-36392.2	12845.3

Cointegrating equations

Equation	Parms	chi2	P>chi2
_ce1	1	4.084576	0.0433

Identification: beta is exactly identified

Johansen normalization restriction imposed

beta	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
_ce1						
GDP	1	.	.	.	.	.
EC	-724269.1	358365.7	-2.02	0.043	-1426653	-21885.15
_cons	3.85e+11	.	.	.	.	.

. vec GDP Coal,lags(4)

Vector error-correction model

Sample: 1982 - 2011 No. of obs=30

AIC =74.16573

Log likelihood = -1095.486 HQIC =74.41974

Det(Sigma_ml) =1.79e+29 SBIC =74.95975

Equation	Parms	RMSE	R-sq	chi2	P>chi2
D_GDP	8	1.8e+10	0.9886	1904.261	0.0000
D_Coal	8	35952.2	0.8390	114.6545	0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
D_GDP						
_ce1						
L1.	.0995196	.0295594	3.37	0.001	.0415842	.1574549
GDP						
LD.	.416832	.2242877	1.86	0.063	-.0227639	.8564279
L2D.	-.6085933	.2529662	-2.41	0.016	-1.104398	-.1127886
L3D.	.1763439	.2269469	0.78	0.437	-.2684638	.6211516
Coal						
LD.	330656.9	128387.2	2.58	0.010	79022.6	582291.1
L2D.	-6715.176	183177.8	-0.04	0.971	-365737	352306.7
L3D.	327219.6	150330.3	2.18	0.030	32577.67	621861.6

_cons	.0130641	5.42e+09	0.00	1.000	-1.06e+10	1.06e+10
D_Coal						
_ce1						
L1.	1.67e-07	5.89e-08	2.83	0.005	5.14e-08	2.82e-07
GDP						
LD.	2.46e-07	4.47e-07	0.55	0.582	-6.30e-07	1.12e-06
L2D.	-1.07e-07	5.04e-07	-0.21	0.832	-1.10e-06	8.82e-07
L3D.	-1.43e-06	4.53e-07	-3.16	0.002	-2.32e-06	-5.43e-07
Coal						
LD.	.3455299	.2559895	1.35	0.177	-.1562002	.84726
L2D.	-.0644123	.3652357	-0.18	0.860	-.780261	.6514365
L3D.	.2204571	.2997415	0.74	0.462	-.3670255	.8079397
_cons	-7654.836	10807.57	-0.71	0.479	-28837.28	13527.61

Cointegrating equations

Equation	Parms	chi2	P>chi2
_ce1	1	1.388086	0.2387

Identification: beta is exactly identified

Johansen normalization restriction imposed

beta	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
_ce1						
GDP	1	.	.	.	.	.
Coal	-510827.3	433576.7	-1.18	0.239	-1360622	338967.5
_cons	1.98e+11	.	.	.	.	.

. vec GDP oil,lags(2)

Vector error-correction model

Sample: 1980 - 2011 No. of obs=32

AIC =72.24422

Log likelihood = -1146.908 HQIC =72.38087

Det(Sigma_ml) =4.63e+28 SBIC =72.65646

Equation	Parms	RMSE	R-sq	chi2	P>chi2
D_GDP	4	2.1e+10	0.9801	1379.346	0.0000
D_oil	4	11762.6	0.5866	1.216369	0.8754

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
D_GDP						
_ce1						
L1.	.0088569	.0028274	3.13	0.002	.0033153	.0143986
GDP						
LD.	.5058656	.1662907	3.04	0.002	.1799418	.8317894
oil						
LD.	-109596.4	376368.5	-0.29	0.771	-847265.2	628072.3
_cons	.000607	5.89e+09	0.00	1.000	-1.15e+10	1.15e+10
D_oil						
_ce1						
L1.	1.49e-09	1.58e-09	0.94	0.346	-1.60e-09	4.58e-09
GDP						
LD.	6.79e-09	9.27e-08	0.07	0.942	-1.75e-07	1.88e-07
oil						

```
LD. |   -.1715669   .2098174    -0.82   0.414    -.5828013    .2396676
    |
_cons |   2298.025   3285.188     0.70   0.484    -4140.825    8736.875
------------------------------------------------------------------------------

Cointegrating equations

Equation           Parms    chi2     P>chi2
-------------------------------------------
_ce1                 1   7.636569   0.0057
-------------------------------------------

Identification:  beta is exactly identified

                 Johansen normalization restriction imposed
------------------------------------------------------------------------------
        beta |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
_ce1         |
         GDP |          1          .        .       .            .           .
         oil |   4.35e+07   1.57e+07     2.76   0.006     1.27e+07    7.44e+07
       _cons |  -4.21e+12          .        .       .            .           .
------------------------------------------------------------------------------
```

. vec GDP ELEC,lags(4)

Vector error-correction model

Sample: 1982 - 2011 No. of obs=30

AIC =73.75847

Log likelihood = -1089.377 HQIC =74.01248

Det(Sigma_ml) =1.19e+29 SBIC =74.55248

Equation	Parms	RMSE	R-sq	chi2	P>chi2
D_GDP	8	1.4e+10	0.9933	3284.002	0.0000
D_ELEC	8	35855.1	0.9800	1077.909	0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
D_GDP						
_ce1						
L1.	.1621987	.032615	4.97	0.000	.0982744	.226123
GDP						
LD.	.1678157	.1993214	0.84	0.400	-.222847	.5584784
L2D.	-.11364	.2613907	-0.43	0.664	-.6259564	.3986764
L3D.	-.6905962	.2571425	-2.69	0.007	-1.194586	-.1866061

ELEC						
LD.	243459.6	58683.49	4.15	0.000	128442.1	358477.2
L2D.	-183531.5	112929.5	-1.63	0.104	-404869.2	37806.26
L3D.	714453.6	115187.2	6.20	0.000	488690.9	940216.4
_cons	.0655516	5.49e+09	0.00	1.000	-1.08e+10	1.08e+10
D_ELEC						
_ce1						
L1.	4.37e-07	8.50e-08	5.14	0.000	2.70e-07	6.03e-07
GDP						
LD.	-1.38e-06	5.19e-07	-2.67	0.008	-2.40e-06	-3.67e-07
L2D.	-9.69e-07	6.81e-07	-1.42	0.155	-2.30e-06	3.66e-07
L3D.	-6.45e-07	6.70e-07	-0.96	0.336	-1.96e-06	6.68e-07
ELEC						
LD.	.995193	.1528747	6.51	0.000	.695564	1.294822
L2D.	-.9430767	.2941895	-3.21	0.001	-1.519677	-.3664759
L3D.	2.126026	.300071	7.09	0.000	1.537897	2.714154
_cons	-24232.2	14312.14	-1.69	0.090	-52283.48	3819.086

Cointegrating equations

Equation	Parms	chi2	P>chi2
_ce1	1	14.65401	0.0001

Identification: beta is exactly identified

Johansen normalization restriction imposed

beta	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
_ce1						
GDP	1	.	.	.	.	.
ELEC	-511308	133568.6	-3.83	0.000	-773097.7	-249518.3
_cons	6.42e+10	.	.	.	.	.

Appendix 5 Granger causality test

5.1 veclmar

Lagrange-multiplier test

```
+----------------------------------------------------------------------
| lag   |          chi2       df      Prob > chi2 |
|------+---------------------------------------------------------------
|     1   |       4.3039         4         0.36643     |
|     2   |       5.8475         4         0.21083     |
+----------------------------------------------------------------------
```

H0: no autocorrelation at lag order

5.2 Short term causality test

. test([D_GDP]:LD.EC L2D.EC L3D.EC)

(1)   [D_GDP]LD.EC = 0

(2)   [D_GDP]L2D.EC = 0

(3)   [D_GDP]L3D.EC = 0

chi2(3) = 26.51

Prob > chi2 =   0.0000

. test([D_EC]:LD.GDP L2D.GDP L3D.GDP)

(1)   [D_EC]LD.GDP = 0

(2)   [D_EC]L2D.GDP = 0

(3)   [D_EC]L3D.GDP = 0

chi2(3) = 13.85

Prob > chi2 =   0.0031

. test([D_GDP]:LD.Coal L2D.Coal L3D.Coal)

(1)   [D_GDP]LD.Coal = 0

(2)   [D_GDP]L2D.Coal = 0

(3)   [D_GDP]L3D.Coal = 0

chi2(3) = 19.74

Prob > chi2 =   0.0002

. test([D_Coal]:LD.GDP L2D.GDP L3D.GDP)

(1)   [D_Coal]LD.GDP = 0

(2)   [D_Coal]L2D.GDP = 0

(3)   [D_Coal]L3D.GDP = 0

chi2(3) = 21.67

Prob > chi2 =   0.0001

. test([D_GDP]:LD.oil)

(1)   [D_GDP]LD.oil = 0

chi2(1) =   0.08

Prob > chi2 =   0.7709

. **test([D_oil]:LD.GDP)**

(1)   [D_oil]LD.GDP = 0

chi2(1) =   0.01

Prob > chi2 =   0.9416

. test([D_GDP]:LD.ELEC L2D.ELEC L3D.ELEC)

(1)   [D_GDP]LD.ELEC = 0

(2)   [D_GDP]L2D.ELEC = 0

(3)   [D_GDP]L3D.ELEC = 0

chi2(3) = 49.09

Prob > chi2 =   0.0000

. **test([D_ELEC]:LD.GDP L2D.GDP L3D.GDP)**

(1)   [D_ELEC]LD.GDP = 0

(2)   [D_ELEC]L2D.GDP = 0

(3)   [D_ELEC]L3D.GDP = 0

chi2(3) = 25.58

Prob > chi2 =   0.0000

초록

중국의 에너지 소비와 GDP 성장간의 관계

지난 30 년간 중국은 급속한 경제 성장을 이루었다. 그 과정에서 에너지는 중국의 발전에 중요한 역할을 담당하였으며, 현재 중국은 세계에서 가장 많은 에너지를 소비하는 국가가 되었다. 1978 년에서 2011 년 사이의 시계열 자료를 바탕으로, 본 논문에서는 중국의 에너지 소비량과 국내 총생산(GDP) 사이의 관계를 분석하였다. 분석 방법으로는 확장 딕키-풀러(Augmented Dickey–Fuller) 및 공적분(co-integration) 검정, 그리고 벡터오차수정모형(Vector Error Correction Model)을 이용하였다. 분석 결과, 가스를 제외한 에너지(석탄,

석유, 전력) 소비와 GDP 사이에는 장기 균형 관계가 있음을 확인하였다. 또한, GDP 와 총 에너지 소비, 석탄과 전력 소비 사이에는 단기 양방향 인과관계가 있으며, 석유 소비는 GDP 로의 장기 단방향 인과관계가 있음을 확인하였다. 한편, 본 논문에서는 GDP 와 총 에너지 소비 사이의 비동조화(decoupling) 경향도 조사하였다. 실증 분석 결과, 중국 경제가 여전히 에너지 소비에 의존하고는 있지만, 동시에 약한 비동조화 경향을 보인다는 주장이 지지되었다. 결론에서는 본문에서의 추정 결과에 따라, 새로운 에너지 자원 탐사와 혁신 속도 가속화에 집중하고 있는 현재 중국 경제성장 정책에 대한 정책적 함의를 도출하였다.

주요어: 공적분; 오차수정모형; 국내총생산; 에너지 소비

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