DEPARTMENT OF ECONOMICS

COLLEGE OF BUSINESS AND ECONOMICS

UNIVERSITY OF CANTERBURY

CHRISTCHURCH, NEW ZEALAND

China's Energy Economy: A Survey of the Literature

by Hengyun Ma and Les Oxley

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Department of Economics
College of Business and Economics
University of Canterbury
Private Bag 4800, Christchurch
New Zealand

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China's Energy Economy: A Survey of the Literature

Hengyun Ma[1,2] **and Les Oxley**[1]

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Abstract This paper reviews literature on China's energy economics, focusing especially on: i) the relationship between energy consumption and economic growth, ii) China's changing energy intensity, iii) energy demand and energy -capital and -labor substitution, iv) the emergence of energy markets in China, vi) and policy reforms in the energy industry. After reviewing the literature, the study presents the main findings and suggests some topics for further study.

Key words: China; Energy; Literature

JEL classifications: D24, O33, Q41

[1] Department of Economics and Finance, University of Canterbury, Private Bag 4800, Christchurch, New Zealand
[2] College of Economics and Management, Henan Agricultural University, 95 Wenhua Road, Zhengzhou 450002, China.

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1. Introduction

1.1 Why China's energy economy matters

It is well known that China is one of the largest and fastest growing emerging economies in the world with this outcome initiated by the reforms of the late 1980s. According to China's Statistical Yearbook (CSY), its GDP growth rate has approximated 10% annually and its aggregate GDP reached 3.1 trillion US dollar by 2006.[1] As a consequence, China's aggregate energy consumption also expanded both in volume and growth rate terms during the same period, especially post 2002. Figure 1, below, demonstrates the historical change of both China's GDP and aggregate energy consumption from 1978 to 2006. It can be clearly seen that GDP grows strongly and consistently, although it does trend downwards between 1996 and 2002, the aggregate energy consumption generally increases consistently with GDP. Apart from the short downward trend, aggregate energy consumption typically tracks GDP after 2002, in fact, the annual growth rate (12.9%) of aggregate energy consumption is slightly higher than that (10.4%) of GDP for the period 2002 to 2006 (CSY, 2007).

With strong growth of GDP and aggregate energy consumption, China has become the second largest consumer of energy products and the third largest oil importer in the world. China's primary energy consumption reached 1863.4 million tonnes oil equivalent in 2006, the second largest consumer after the USA (BP, 2008). More importantly,

[1] Exchange rate of Chinese yuan to US dollar is 6.9:1 on the 2006 price base.

China's global shares of primary energy consumption have increased dramatically since 1978, especially after 2002, see Figure 2. It can be seen from Figure 2 that the global shares of primary energy consumption were only 6.3% for China and as high as 28.6% for the USA in 1978. However, China's global share of primary energy consumption soared to 16.8%, in 2007. In contrast, the USA's global share of primary energy consumption decreased dramatically to 21.3% in 2007.

Due to its rising energy demand, China has had to import large quantities of oil to meet its domestic demand. Despite being a net exporter of petroleum in 1990, China's import share of petroleum dramatically increased from less than 8% in 1995 to approximately 50% in 2006 (Figure 3). By 2007, China's imports of crude oil and products reached 184 million tonnes, becoming the third largest importer after USA and Japan (BP, 2008).

There are many factors that require China to import more petroleum products. Of them, household car ownership is one of the most important. Private car purchases have increased rapidly. In 2000 there were only 0.5 cars per hundred urban households. By 2006 this figure increased to 4.32 (CSY, 2007). The rise in electricity consumption has been driven not only by rapidly growing industrial demand, but also an even more rapidly spreading ownership of household appliances (Smil, 1998). For example, household air conditioners and microwave ovens have trebled during in the last six years, from 30 and 17 to 88 and 51 per hundred urban households, respectively. As a result, household electricity consumption has expanded rapidly. Household electricity consumption was 48 billion KWh in 1990, doubling to 101 billion KWh in 1995 and doubling again to 201 billion KWh by 2002. In 2006 this figure had risen to nearly 325 billion KWh. As a consequence, there has been a growing shortage of electricity in China which has attracted both growing interest and concern (see Lin, 2004).

Raw coal production accounts for most of China's primary energy supply and electricity production is mainly generated from coal. This raises considerable environmental issues. One of the features of China's energy consumption is its overwhelming share of raw coal in aggregate energy consumption. During the past three decades, China's share of raw coal consumption remained steady at 70% of aggregate primary energy consumption (Table 1, column 1). By 2006 this had risen to approximately 77% (column 2). Raw coal is the most important source of electricity where in the last three decades over 80% of electricity consumed was generated from burning raw coal (column 3). Electricity from hydro, nuclear and wind accounted for only 8%.

Following three decades of rapid economic growth and rising demand for energy products, Chinese residents are now becoming more environmentally aware. Consequently, policy makers have begun to acknowledge the need for cleaner sources of energy, such as natural gas and hydro. Continued movements in this direction will see the share of coal in total energy consumption decline further, with the share of oil, gas, and hydro increasing rapidly. This will push China to import more oil with significant effects on global energy markets (Crompton and Wu, 2005).

However, raw coal remains the most important energy source in China. Therefore, China may face more severe challenges in dealing with future environmental issues than most rapidly developing countries. Given the size of the economy and its current growth rates and its special features of energy economy, any changes in industrial structure, energy price deregulation, technological progress and improvements in energy efficiency in China will produce a significant effect on the global energy market. Therefore, China's energy economy does matter nationally and globally.

1.2 China's energy economics is still in its infancy

Compared with its global importance, China's energy economy is less developed and less fully understood in an international sense. Despite some areas having been extensively investigated for example, the relationship between energy consumption and economic growth, and changes in energy intensity, many other important issues, including energy price convergence; energy demand; energy-other factor substitution, and energy economic studies at the disaggregate level, have not been extensively studied or, in some cases, considered at all.

It can also been seen that many empirical studies of Asian or developing country's energy economies exclude China from their analysis for example, Mahadevan and Asafu-Adjaye (2007) investigate energy consumption, economic growth and prices for 14 developing countries excluding China. Likewise, Lee and Chang (2007) study the relationship between energy consumption and GDP growth for 18 developing countries, but also exclude China. Table 2 lists a number of other papers on Asia which exclude China. The reasons are unclear, but may include data availability, but it is still an extraordinary omission.

Energy policy reforms play an important role in the development of China's energy economy. China has introduced numerous measures to rationalize oil, coal, gas and electricity prices since the early 1980s. At the same time, China's energy reforms have attracted great attention from both domestic and international researchers. There are many studies relating to China's energy reforms, including regulatory and the pricing system. For example, Andrews-Speed, Dow and Gao (2000), Xu and Chen (2006), Cherni and Kentish (2007), and Ma and He (2008) discuss the ongoing regulatory reforms to China's energy industry at the government and state sector level. Wu (2003), Wang (2007) and Hang and Tu (2007) address price deregulation reforms over time. All these studies, however, simply introduce and describe the institutional reform programs to China's energy industry. In particular, they do not econometrically or analytically assess any potential effects of those reform programs on the development of China's energy economy or the economic growth implications. As a consequence, what we see is a series of slow, incremental and gradual policy reforms to China's energy industry, often applied in an ad hoc and partial, non integrated, way.

1.3 The need for a survey of China's energy sector

Given the importance and rapid pace of economic growth and the special features of energy consumption and trade, there appears to be a need to create an up-to-date and critical assessment of information on China's energy economy. This information, which will be both factual and a survey of the literature written, to date, on the energy sector, will inform both academic and political decision making including, crucially, those relating to environmental issues. Because of the political importance of energy, leaders in all countries have typically demanded that predictions be made on energy efficiency, energy consumption and energy trade. Those charged with negotiating and managing China's energy trade agreements, including the nation's top leaders, also require accurate predictions about future energy demand, imports and crucially impacts on economic growth, employment and increasingly, the environment. More importantly, researchers who consider the energy economy need to know what has been done well and what has not; what resources they can access to conduct research on China's energy economy and which of these are robust. To date, however, there has been no such review paper available to researchers or policy makers and this paper is motivated to fill that gap. Consequently, this survey will review the existing research and help facilitate future research to better understand and study China's energy economy.

The review is organized as follows. Section 2 outlines the main topics to be reviewed and approaches used in the review. Section 3 reviews previous studies on China's energy economy arranged into four topics: i) economic growth and energy consumption, ii) China's changing energy intensity, iii) energy demand and factor substitution, and iv) energy price convergence in China. Section four presents a summary of the main findings. The final section provides some policy implications and presents some ideas for future research.

2. The topics to be reviewed and the approaches used

2.1 The topics to be reviewed

The energy sector covers a range of activities including energy trade, energy production and employment, energy pricing, energy taxes, and environmental regulation, etc.

However, a single review paper cannot address all these elements in a large and complicated economy like China. Therefore, this review will focus on five topics specifically: i) the relationship between energy consumption and economic growth, ii) China's changing energy intensity, iii) energy demand and energy -capital and -labor substitution, iv) the emergence of energy market in China, vi) and policy reforms in energy industry. The reasons that we have chosen these five topics are firstly, most of the existing energy economics literature covers these five topics. Secondly, most of papers published in energy economic journals for example, *Energy Economics, Energy Policy, The Energy Journal*, predominantly include these topics. Thirdly, they are five of the most popular and the most extensively investigated topics. Finally, other respects, such as energy trade, energy production, etc, are also important, but these topics are rarely found in energy economic journals, instead they appear in either specialist production journals or the introductory sections of energy economic papers.

2.2 The organizing approaches used in this survey

To organize this review, we first provide a table of existing major studies on the Chinese energy economy for each of four topics listed above. We first observe, summarize and analyze their focus and results to ascertain whether there are any differences across the studies. We then discuss the possible reasons for the differences one by one in the order of approaches, period or time span, data source and assumptions if available. After reviewing each topic, we summarize the issues that need to be addressed, the future work required, etc. After reviewing all four topics, we present a summary of our main findings and some policy implications. Finally, we conclude our review by suggesting future areas of study on the Chinese energy economy.

3. Review of studies on China's energy economy

3.1 Energy consumption and economic growth

Here we first look at the existing literature in the relevant areas and then, we present some new results we have prepared in relation to: i) National aggregate energy consumption v.s. national aggregate economic growth; ii) National disaggregate energy consumption v.s. aggregate economic growth; iii) Provincial aggregate energy consumption v.s. aggregate economic growth; iv) Provincial disaggregate energy consumption v.s aggregate economic growth; v) National industrial aggregate energy consumption v.s. economic growth; vi) Provincial industrial aggregate energy consumption v.s. aggregate economic growth.

3.1.1 What do existing surveys of the literature show?

During the 1990s, China's economic growth and energy consumption did not attract much attention either domestically or internationally. When Tang and Croix (1993) reviewed the interaction between energy use and economic growth in China, they only found two studies on the role of energy sources in China's economic development; Smil (1988) and Owen and Neal (1989). The former provided an insightful analysis of the role of energy in China's economic development since 1949; the later examined the extent of China's energy resources and the potential for energy exports.

Since the 1990s, however, China's energy consumption and economic growth has attracted attention from both domestic and international researchers where the relationship between China's energy consumption and economic growth has been extensively investigated and analyzed. Table 3 lists papers that have previously reviewed China's energy consumption and economic growth interactions and implications.

Zhao and Fan (2007) conclude that the relationship between energy consumption and economic growth varies across countries or regions and even during different phases due to the changing priorities given to energy and economic policies in the course of economic development. They were critical of the papers they reviewed (Table 3, row 1) that assumed a linear relationship between energy consumption and economic growth without conducting any statistical tests of the linearity assumption between economic growth and energy consumption. As a result, they estimate a nonlinear relationship between economic growth and energy consumption by employing a smooth transfer regression analysis (STR).

Liu, Ceng and Liu (2006) state that the Chinese literature reviewed in their paper (row 2) follows the approaches of the literature published in English and they then apply their methodologies to study China's energy economics where they ultimately come to the same conclusions. They estimate an extended Cobb-Douglas production function, incorporating energy as an input, and find that from 1985 to 2003 GDP increases by only 1.4-2.8% following a 10% increase of energy consumption.

Liu (2007) finds that the studies he reviewed (row 3) only focus on aggregate energy consumption and not disaggregated energy use. He then conducts cointegration analysis on economic growth and petroleum consumption, finding that there is no causal relationship between economic growth and petroleum consumption in China.

Guo (2007) also states that the studies he reviewed (row 4) focus on energy consumption and economic growth without taking into account technological change. Therefore, he incorporates technological factors into his growth model and considers technologies embodied in energy and labor.

Similarly, Wang and Yang (2006) argue that those studies they reviewed follow traditional time series approaches and focus only on aggregate data. As a result, in their study, they conduct panel cointegration analysis for twelve major industries of China.

As can be seen from the partial review above, previous papers are often incomplete or partial because they were chosen and reviewed only as a means to introduce their own work. Based on these papers it is difficult to have a clear, balanced and up-to-date knowledge of China's current energy economy.

3.1.2 What can be learned from this survey?

Here we present Table 4-1, Table 4-2 and Table 4-3 that show the papers to be reviewed and approaches, results, etc. As stated previously, Table 4-1 lists the studies that focus on the relationship between national aggregate energy consumption and aggregate economic growth. Table 4-2 presents the studies that focus on the relationship between disaggregate energy consumption and disaggregate or aggregate economic growth. Table 4-3 presents the articles that focus on national industrial aggregate energy consumption and aggregate economic growth. It can be seen that Table 4-1 is also sorted by time period which will affect methods used, etc and potential changing foci of the papers as issues develop.

3.1.2.1 The focus of existing studies

From Table 4-1, Table 4-2 and Table 4-3, we can observe that the studies to be reviewed focus on six themes. However, most papers focus only on national aggregate energy consumption and aggregate economic growth (Table 4-1).

Some focus on national aggregate energy consumption and national disaggregate economic growth (Table 4-2). A few studies focus on provincial economy (Table 4-2, bottom) and national disaggregate economy (Table 4-3).

It is clear, therefore, that the relationship between energy consumption and economic development at the provincial level has not been extensively investigated. Likewise, the relationship between energy consumption and economic development for primary and tertiary industries has not attracted scholarly attention.

3.1.2.2 The results from existing studies in this survey

Generally, we can find five types of results from existing studies of the relationship between energy consumption and economic growth:

- Causal relationships between energy consumption and economic growth;
- Long-term cointegration based on Engle-Granger or Johansen-Juselius cointegration tests;
- Long-term elasticities of energy input and income (per capita GDP) derived from C-D production function;
- Short-term error correction coefficients; and
- Other elasticities from long-term cointegration tests and short-term dynamic adjustment (ECM) at national or disaggregate economy levels.

We first consider Table 4-1 where three kinds of results can be ascertained. Most studies presented there show a causal relationship between energy consumption and economic growth. These causal relations can be classified into three groups. The first is that energy consumption Granger causes economic growth. Papers here include Zhao and Fan (2007), Chan and Lee (1996), Lee and Chang (2008), Wang and Liu (2007) and Huang and He (2006). The second group considers whether economic growth Granger causes energy consumption. Papers here include Zhang and Li (2004), Fan and Zhang (2005), Wu, Cheng and Wang (2005), Wang and Yao (2007), Wang and Yang (2007), Liu (2006) and Liu, Liu and Pan (2007). The third group concludes that economic growth and energy consumption Granger cause each other, i.e., bi-directional causality. The papers here include; Ma, Wang, He and Li (2004), Yuan et al. (2008) in Press and Han et al. (2004).

It is clear, therefore, that different findings can be found across the studies. On occasion, the causality results conflict across studies even for the same time periods for example, Ma, Wang, He and Li (2004) find that the relationship is bi-directional for the period 1954-2002 while Wang, Tian and Jin (2006) find that the relationship varies ,1953-2002. Liu (2006) find that the causal relationship is from energy consumption to GDP growth, while Huang and He (2006) find the opposite for the same time period, 1985-2003.

Similarly, many studies conclude that there is a long-term cointegrating relationship between energy consumption and economic growth. However, the estimated elasticities of energy input derived from Cobb-Douglas production function differ significantly ranging from a minimum of -1.06 (Guo, 2007) to a maximum of 0.88 (Lin, 2001) However, all the elasticities of energy input are less than unity, some are very small, for example, the elasticity of energy input is only 0.06 estimated by Lei, Yang and Wang (2007). These elasticities indicate that a 1% increase in energy consumption leads to significantly less growth in GDP growth than this 1% increase.

Turning to national disaggregate energy consumption and aggregate economic growth (Table 4-2), a similar story emerges. Firstly, the observed relationship between national coal consumption and economic growth shows differing causal relationships. Despite a very similar sample period Wang and Yang (2007) find that national aggregate economic growth Granger causes coal consumption from 1978 to 2005, but national aggregate economic growth and coal consumption Granger cause each other from 1980-2004.

Next consider the long-term relationships between national oil or petroleum and national aggregate economic growth. The results here are also mixed. Both Zou and Chau (2006) and Yuan et al (2008 in Press) find that a bi-directional causal relationship between national oil or petroleum and national aggregate economic growth. However, Liu (2007) concludes there is no causal relation between them, 1953 to 2004. In addition, Zou and Chau (2006) find that oil consumption Granger causes GDP growth from 1953 to 2002. A long-term cointegrating relationship between petroleum consumption and national aggregate economic growth is found by Ni and Ling, (2005) with a 0.68 elasticity of energy input from 1977 to 2002.

Finally, the results presented on the long-run relationship between national electricity consumption and aggregate economic growth are also highly variable. Most studies find a bi-directional causal relationship between electricity and economic growth (Wang, Tian and Jin, 2005; Yuan et al., 2008; Chen, Ma and Qin, 2007; Yuan et al., 2007), however, Shiu and Lam (2007) conclude that national electricity Granger causes aggregate economic growth. Huang (1993) suggests that there is long-run cointegration between national electricity consumption and aggregate economic growth and estimates a large income elasticity (per capita GDP), which most likely indicates that income growth did drive electricity consumption increases before 1980. However, Lin (2003ab) estimates an income elasticity (per capita GDP) of approximately 0.8, which suggests that income growth doesn't drive electricity consumption post 1980.

Wang and Yang (2006) estimate a series of both long-run cointegration and short-run dynamic adjustment for twelve industries (Table 4-3). It is clear that some industries play a crucial role in reducing energy consumption by improving their energy efficiency, such as ferrous metals processing, petroleum processing and coking, electricity steam and water, nonferrous metals processing, chemical and nonmetal mineral products. Their efficiency elastisities range from -42 to -24. This means that the energy consumption will decrease by 42-24% given a 10% increase of industrial energy efficiency in the long-run (top, column 3).

A similar pattern can be found for the effect of a short-run energy efficiency improvement on the reduction of energy consumption. These industries again include ferrous metals processing, chemical, nonmetal mineral products, nonferrous metals processing, electricity steam and water, and petroleum processing and coking. The estimated elasticities show that energy consumption decreases by 50-30% given a 10% increase of industrial energy efficiency in the short-run (bottom, column 2).

3.1.2.3 Why do the results differ?

The reasons why the reported relationships between energy consumption and economic growth in both long-run and short-run differ across studies is unclear, possibilities include variations in methods used, time periods studied and importantly data sources.

3.1.2.3.1 Do the methods used matter?

There are various methods used to model the relationship between energy consumption and economic growth in the long-run and short-run (refer to Table 4-1, Table 4-2 and Table 4-3 above). Typically, the methods can be categorized into two groups. Group One is traditional time series methods including ADF tests, Engle-Granger cointegration, Vector Error Correction Models (VECM) and Granger causality. As can be seen from Table 4-1, Table 4-2 and Table 4-3, these methods are extensively used.

Group Two includes modified time series methods, production function analysis and 'other approaches'. For example, Error Correction Model (ECM) plus the Hodrick-Prescott filter (Yuan et al., 2007); panel data cointegration using fully modified ordinary least square (FMOLS) based on a three inputs (capital, labor and energy) production function (Lee and Chang, 2008); generalized forecasting error variance decomposition and generalized impulse response analysis (Liu, Liu and Pan, 2007); smooth transfer regression assuming a nonlinear relationship (Zhao and Fan, 2007); time varying parameter approaches based on state space models (Wang, Tian and Jin, 2006),[2] and C-D

[2] For state space model refers to Hamilton (1994).

production functions (Liu, Ceng and Liu, 2006; Lei, Yang and Wang, 2007; Dong and Du, 2007).

One might expect that the type of estimation method should not effect the conclusions dramatically, however, empirically this is not the case Wang and Liu (2007) and Wang and Yang (2007) use the same time period and time series methods, but they produce the opposite results (Table 4-1). The reasons are not obvious.

3.1.2.3.2 Does the time period studied make a difference?

The time period used is the most likely reason why estimated relations differ across studies. This can be expected from Figure 1 which shows that national aggregate energy consumption and GDP growth have different trends over different sub-periods. Prior to 1996 the trends coincide, but then energy consumption starts to decline from 1997 while GDP maintains the same pace of growth. Energy consumption starts to climb from 2002, but GDP grows a faster than past trend until 2006. For the purpose of this review, therefore, we cannot easily conclude whether the variation in results come from the different periods, as most studies mix different development stages.

3.1.2.3.3 Do the differences arise from data sources?

Data may be the least likely reason for differences as most studies use the national aggregate data which is readily available, however, data transformation is another potential reason for differences. Some studies use logarithms, others not. This will affect measures such as short and long run elasticities for example, the contradictory results from Wang and Liu (2007) and Wang and Yang (2007) may arise from such a data transformation issue (Table 4-1).

3.1.2.3.4 Does the coverage of independent variables matter?

The choice of independent variables is another potential reason why results differ in part because of possible omitted variable bias. Some studies include three input variables (Lee and Chang, 2008; Yuan et al., 2008 in Press), while others only include one energy input variable (Chan and Lee, 1996; Tang and Croix, 1993 and Zou and Chau, 2006; Yuan et al., 2007; Huang, 1993). Other relevant variables include the incorporation of variables to proxy technological change (time) in the model. Estimates that suggest a large negative elasticity of energy input may be due to the incorporation of technological variables in the model (e.g., Guo, 2007).

The studies discussed above have made a contribution to our understanding of China's energy economy, however, it is hard to be confident which relationship actually exists between national aggregate energy consumption and aggregate economic growth in China as it seems impossible to derive a consistent set of results based on the studies reviewed. There are several comments at this stage:

a. There is a need to distinguish between different stages of economic development and identify the major factors or policy reforms in place at the time which may have had a significant effect on energy consumption and economic growth. It may be helpful, therefore for policy reform dummy variables to be incorporated into the various models.
b. There may be a need to break long time periods into different, shorter periods as long periods have the potential to mix the different stages of economic development and some policy reforms variables may be incorrectly treated

econometrically if the time span is too long. For example, in the early stages of economic development, energy consumption may Granger cause economic growth. However, economic growth may Granger cause energy consumption for more developed economies. If the time periods are combined the net effect may be to show no causality or bi-directional causality.

c. Most studies focus on the study of energy consumption and economic growth at the national level. Little attention is paid here to the study of the relationships between energy consumption and economic growth at the provincial level. A recent study by Ma et al. (2008) shows that there are significant differences in the determinants of the changes in energy intensity across regions in China. This likely means that, for policy purposes, it is unlikely that national level results will be helpful.

d. Long-run relationships between energy consumption and economic growth are important, however, the short-run relations may be different and more crucial. Unfortunately, of the literature pays little attention to this matter. Table 4-1 shows that a large number of studies did not present any results on the short-run dynamic relation between energy consumption and economic development.

e. China has undergone radical economic and social change. It is crucial, therefore, that any studies of China's energy economy are cognizant of such changes and that attempts be made to incorporate proxies and measures of these changing economic development and policy reforms.

3.2 China's changing energy intensity

The 1973 world petroleum crisis led to a worldwide evaluation of energy efficiency and generated various strategies for national energy development. As a result, more and more energy related departments and agencies have studied energy efficiency. The Office of Energy Efficiency and Renewable Energy of the United States Department of Energy (OEERE, 2005), for example, created a new system of indexes of energy intensity which were designed to measure the change in national energy efficiency and that of strategic industries. A series of Energy Efficiency Trends in Canada published by Canada Natural Sources Committee systematically analyzes and assess changes in Canadian energy efficiency trends (NRC, 2005). Moreover, the International Energy Agency began to explore energy efficiency assessment indicators in 1995 and currently publishes a series of reports of energy efficiency for OECD countries (IEA, 2004).

There has been considerable debate, however, about the major factors responsible for the apparently dramatic decline in energy intensity. Garbaccio, Ho and Jorgenson (1999) stated that energy consumption per unit of GDP fell by 55% from 1978-1995. Other scholars have been concerned to explain China's energy intensity change. For example, Qi, Chen and Wu (2007b) argue about the measure of energy intensity in China. Garbaccio, Ho and Jorgenson (1999) question why the energy-output ratio has fallen in China. Zhang (2003) argues that China's industrial energy intensity fell in the 1990s. Fisher-Vanden, Jefferson, Liu and Tao (2004) are curious what is driving China's decline in energy intensity. Liao, Fan and Wei (2007) want to know what induces China's energy intensity to fluctuate. Moreover, as R&D in energy economy develops, many projects in social sciences and energy efficiency have been launched to investigate China's energy economy performance this century. The National Nature Science Foundation of China (NSFC) financed many projects on energy intensity during this period and, as a consequence, China's energy intensity has been extensively investigated.

To organize this section, we first introduce the definition of energy intensity typically used. Next we review the main methods that are currently used to decompose the change in energy intensity and provide a very simple evaluation of these applications. Then we review the studies on China's change in energy intensity. Finally, we present some comments, suggestions and implications.

3.2.1 The definition of energy intensity

Energy intensity (I) is typically defined as the ratio of energy consumption (E) to output (Q) using Gross Domestic Product (GDP). Empirically, however, there are several different definitions used for example, the energy coefficient, which is the ratio of the annual growth rate of energy consumption to the annual growth rate of GDP, is typically used as a measure to assess energy efficiency. Likewise, energy elasticity, which is the ratio of the first derivative of energy consumption to the first derivative of GDP, is also used as a measure of the change in energy intensity (Zhou, Ang and Zhou, 2007). Although, there are various definitions of energy intensity, all of them should measure the same relationship or ratio between energy consumption and economic growth. Here, we always use the definition of energy intensity defined as the ratio of energy consumption to GDP or value-added, namely, $I = E / Q$.

3.2.2 Methods used to decompose energy intensity

The most popular method used to measure the change in energy intensity and identify the contribution share of its determinants is the index decomposition approach. Since its introduction in the late 1970s to study the impact of structural change on energy use in industry, index decomposition analysis has been extensively used for policymaking as its simplicity and flexibility makes it easy to adopt (Ang, 2004). The typical index decomposition of energy intensity is defined as follow:

(1) $I = E/Q = \sum_{i=1}^{k} E_i / Q = \sum_{i=1}^{k} (Q_i / Q) \times (E_i / Q_i) = \sum_{i=1}^{k} S_i \times I_i$

Where I is a comprehensive energy intensity; E is aggregate energy consumption; Q is aggregate output (GDP); E_i is energy consumption for the ith industry; Q_i is individual industrial output (value-added); S_i is the share of individual industrial output, and $S_i = Q_i / Q$; I_i is energy intensity for the ith industry, and $I_i = E_i / Q_i$. Equation (1) implies that aggregate energy intensity is determined by individual industrial energy intensity and its output share. In this case, the change in aggregate energy intensity is decomposed into two components, one due to individual industrial energy intensity and the other due to its output share.

As there are various definitions, the index decomposition approach can be categorized into two types: definitions related to the Laspeyres index and definitions related to the Divisia index (Ang, 2004). The basic feature here is that the Laspeyres index demonstrates the additive relationship amongst the decomposed components, while the Divisia index uses the multiplicative relationship between the decomposed components. In additive decomposition, the change (ΔI) in aggregate energy intensity can be decomposed as follow:

(2) $\Delta I = I^t - I^0$

and empirically, it can be further decomposed into two components:

(3) $\Delta I = \Delta I_{\text{int}} + \Delta I_{str}$

Where, superscripts t and 0 represent report year and base year, respectively; $\Delta I_{\text{int}} = \sum_i^k S_i^t (I_i^t - I_i^0)$ and $\Delta I_{str} = \sum_i^k I_i^0 (S_i^t - S_i^0)$ are the absolute effects of industrial energy intensity change and industrial structural shift on aggregate energy intensity, respectively. Correspondingly, dividing them by the change (ΔI) in aggregate energy intensity provides their contribution shares. Note that in the additive form the decomposed results are given in the unit in which the aggregate energy-intensity is measured. They are easy to interpret.

In multiplicative decomposition, the ratio (D_I) in aggregate energy intensity can be decomposed as follows:

(4) $D_{tot} = I^t / I^0$

and empirically, it can be further decomposed into two components:

(5) $D_{tot} = I_{\text{int}} \times I_{str}$

Where $I_{\text{int}} = \sum_i^k S_i^t I_i^t / \sum_i^k S_i^t I_i^0$ and $I_{str} = \sum_i^k I_i^0 S_i^t / \sum_i^k I_i^0 S_i^0$ are the relative effects of industrial energy intensity change and industrial structural shift on the relative change (D_{tot}) in aggregate energy intensity, respectively.

The above discussion provides revision of the basic principles of index numbers. Equation 2 and equation 5 provide the governing forms for decomposing aggregate energy-intensity. For a given set of data the application of different decomposition methods leads to different estimates of the terms on the right hand side of the equations.

There are, for example, Multiplicative ArithLetic Mean Divisia indices (MAMD), Arithmetic Mean Divisia Indices (AMDI), and Logarithmic Mean Divisia indices (LMDI). For detailed decomposition formula and a discussion, see Ang (2004, 2005) and Liu and Ang (2003).

In addition to index decomposition, other methods have also been used to study China's energy intensity. For example, Wang (1999) and Wang (2003) use the input-output approach and Zhang, Ding and Yin (2007) use panel data regression models to investigate the effect of structural change on China's energy intensity change.

3.2.3 What can be learned from existing studies?

Here we first present a table that lists the studies to be reviewed. The table is first arranged by economic or industrial disaggregation and then sorted by time period. Finally, we start our analysis by identifying comparing the estimated results across similar levels of economic disaggregation and similar time periods.

3.2.3.1 Disaggregation of the economy

Depending on the type of index decomposition used, researchers need to disaggregate the whole economy into various industries or sectors and calculate the energy intensity and output shares by industry or sector and by year. From Table 5, column 1, we can see that most studies disaggregate the economy into 3 or 6 industries. Some studies further disaggregate each industry into sectors. Three-industry disaggregation normally includes: i) primary industries, covering agriculture and related activities (farming, forestry, husbandry, secondary production and fishing); ii) secondary industries, covering mining, manufacturing, water supply, electricity generation and supply, steam the hot-water and gas, and construction; iii) tertiary industries, covering transportation (postal and telecommunications services), commerce and others. The more disaggregation the more determinants of the change in energy intensity can be derived. This can be seen from Table 5 where some studies disaggregate further into more than 30 sectors.

It is noted here that almost all studies focus on the national level energy intensity and industrial disaggregation. It is hard to find any that focus on disaggregation at the regional economy level. There appears to be only one provincial energy intensity study – the case of Guangdong province by Yu (2007).

3.2.3.2 The distribution of contribution shares

According to the definition of energy intensity and industrial disaggregation used, more disaggregation can lead to more determinants of the change in energy intensity. However, no matter how the disaggregation is achieved there are only two types of components that determine the change in energy intensity, namely, individual industrial or sectoral energy intensity and its output shares. Therefore, in Table 5, we only present the contribution share of individual industrial or sectoral energy intensity (I_i) and structural change (S_i). In addition, the negative contribution share measures the percentage of energy intensity decline, while a positive contribution share measures the percentage of energy intensity increase. There are several points to note about the results shown in Table 5:

a. Most of studies identify decreasing energy intensity during their study periods. For example, those whose study periods ending in 2000 including Qi, Chen and Wu (2007a), Han, Wei and Fan (2004), Qi and Chen (2006), Gao and Wang (2007) Zhang and Ding (2007), Shi (2007), Zhang (2003), Fisher-Vanden et al. (2004).

However, some studies show rising energy intensity during their study periods (e.g., Qi and Chen, 2006; Gao and Wang, 2007; Ma and Stern, 2008; Zhang and Ding, 2007; Zhou and Li, 2006; Shi Fu, 2007).

b. Some studies show that declining industrial energy intensity plays a larger part in reducing aggregate energy intensity than structural changes, while some studies show structural changes play a role. What is the explanation? Looking at these two groups of studies shows they belong to different eras. In the 1990s or later industrial energy intensity plays a larger part (Qi, Che and Wu, 2007a; Han, Wei and Fan, 2004 last one; Ding et al., 2007; Qi and Chen, 2006; Gao and Wang, 2007; Ma and Stern, 2008 first two; Zhou and Li, 2006 second; Zhang and Ding, 2007; Shi, 2007; Zhang, 2003). In the 1980s or before structural change plays a larger part (e.g., Smil, 1988; Han, Wei and Fan, 2004; Kambara, 1992; Zhou and Li, 2006; Fisher-Vanden et al., 2004). Of course, there are some exceptions.

c. All study periods except that of Qi, Chen and Wu (2007a) that start this century show rising energy intensity (e.g., Qi and Chen, 2006; Gao and Wang, 2007; Ma and Stern, 2008; Zhang and Ding, 2007; Zhou and Li, 2006; Shi Fu, 2007). These results seem consistent with the trend of energy intensity (Figure 4).

d. All results in these studies are very consistent although there are some variations reported when disaggregated data are used or the time period varies.

e. Comparing the results from the existing studies and the patterns of economic growth and energy consumption (Figure 1), we may conclude that: i) before the1990s industrial structural change plays a larger part in the decrease of aggregate energy intensity, while after the 1990s it is the decreasing individual industrial energy intensity that plays a larger part in the decrease of aggregate energy intensity; ii) aggregate energy intensity declined steadily before 2002, but after 2002 it started to increase, but had little change then until 2006;

f. The reasons that aggregate energy intensity decreased after 2002 cannot be easily ascertained based on the existing studies as their results are mixed. For example, the contribution shares of individual industrial energy intensity and industrial structural change are 42:58 (Qi and Chen, 2006), 70:30 (Gao and Wang, 2007), 46:54 (Ma and Stern, 2008), 20:80 (Zhang and Ding, 2007), 55:45 (Zhou and Li, 2006) and 69:31 (Shi, 2007). However, the ideal distribution of contribution share might be 50:50 (Table 5).

g. Given the observations and comparisons above, the existing studies reviewed have reached a fairly consistent view on the change in and determinants of aggregate energy intensity of China, even though various definitions of index decomposition and methods are used.

3.2.4 Some observations

3.2.4.1 On the index decomposition approach

a. The term 'decomposition' simply means disaggregating the economy into industry or sector and then weighting the industrial or sectoral energy intensity (I_i) by their output shares (S_i). That is, it is actually a nonparametric, weighted average. However, it is hard to derive an economic explanation of the change in energy intensity based on the index decomposition approach. Moreover, whether the change in energy intensity is due to technology, growth of income, energy price, urbanization, and consumption behaviors is also impossible to ascertain.

b. There is little basis for choosing one over the other definition. Howarth et al. (1991) demonstrates this using manufacturing data from OECD countries. The differences between estimates of relative shares of industrial structural change and real intensity change are minimal (Sinton and Levine, 1994). Greening et al. (1997) compare six index decomposition methods applied to aggregate energy intensity for manufacturing in ten OECD countries and the results display little significant variations across the six approaches (refer to Figures 1-3 and table 2 of Greening et al. 1997). In fact, the results from existing studies that have been reviewed show few significant differences across the definition of index decomposition (see Table 5).

3.2.4.2 On the variations of results after 2000

What is driving the change in energy intensity after 2002 is still unclear based on the results of existing studies. In this case, further investigation into the changes in national aggregate energy intensity is required. Empirically, it may be better to break a long period energy intensity change into various homogeneous stages before engaging in any index decomposition of energy intensity. For example, measuring the change in energy intensity over the period 2000-2005 may not make sense as half the period shows an increasing trend while the other and half shows decreasing energy intensity.

3.2.4.3 On the comparison of energy intensity internationally

It is probably better to define energy intensity as the ratio of energy consumption (physical units) to output (physical units). Empirically, it is convenient to compare energy intensities across countries and here we are drawn to use aggregate energy intensity calculations. However, comparing aggregate energy intensity raises questions namely, how to measure output and which price to use? Qi, Chen and Wu (2007b) question how high energy intensity is in China. It is clear that aggregate energy consumption is fixed because of the physical units used, while aggregate output calculations are affected by the price used. It might be expected that aggregate energy intensity is lower if it is measured by current price rather than the price ten years ago for example. No matter what prices are used, it doesn't raise any issues if one only observes the change in national aggregate energy intensity. However, the issue arises when aggregate energy intensity comparisons are made internationally. This involves the use of PPP, which is beyond the scope of this survey.

3.3 Energy demand and energy-other factor substitution

Unlike the previous two topics considered above, there are few studies of factor demand and substitution between energy and other factors the exceptions include Ma et al. (2008) and Fan, Liao and Wei (2007). Therefore, we first introduce the existing studies and then provide a short summary.

3.3.1 The existing studies on energy demand and factor substitution

Table 6 provides results for all studies on this topic ordered first by country then scope of study, time period, methodologies and finally the empirical results. Qian and Wang (2003) estimate the elasticity of energy-labor substitution using a Cobb-Douglas production function and national aggregate economy time series data. Their estimates are -0.863 for 1993-2000 and 0.117 for 1979-1992 and suggest energy and labor are complementary for the period 1993-2000, but substitutes in the earlier period.

Zheng and Liu (2004a)[3] estimate the elasticity of substitution between energy-capital and energy-labor employing both CES and C-D production functions with and without technological progress assumptions. Their estimated elasticities of substitution of energy-capital are infinite based on the first order CES production function either with or without a technological progress assumption. However, their estimated elasticities of substitution of energy-capital are unity based on the C-D production function either with or without a technological progress assumption. Clearly those elasticities are only for the extreme cases and they may not exist in reality due to the restrictive assumptions required. In other work, Zheng and Liu (2004b) estimate the substitution of energy-capital and energy-labor employing a second-order translog production function using capital, energy and labor as inputs with technological progress assumptions based on the 1978-2000 national aggregated time series data (output-real GDP, inputs-capital, energy and labor) from various China's Statistical Yearbooks. Their estimated elasticities of substitution between factors are fairly stable over time, but the elasticity of substitution between capital and energy is > 2.50. Energy and labor are also substitutable with an elasticity of only 0.50. It is apparent that there are substantial differences in the estimation of elasticities of substitution of capital-energy between Zheng and Liu's two papers. The reason as stated in Zheng and Liu (2004b) may be due in part to different function definitions implying

[3] They represent the Center for Contemporary Management and Institute of Global Climate Change, Tsinghua University, Beijing, China, which is the third most important institute for the study of Chinese energy economics.

that the second-order translog production function is better able to reveal the real relation between factors than the CES or C-D production functions. However, the estimated elasticity of substitution of energy-capital even based on the translog production function is much larger than those estimated for other countries (Table 6, second half section).

Huang and Huo (2006) also estimate the elasticity of energy-capital substitution using a second order CES production function. Their estimate is 0.685 for national aggregate economy-based data. Compared to Zheng and Liu (2004a and 2004b), their estimate seems more reasonable. Unfortunately, they didn't provide the estimates of the elasticity of energy-labor substitution.

The group of Fan, Liao and Wei first study the substitution of energy and other factors in 2007. Following the reforms of product factor markets and prices, Fan, Liao and Wei (2007) break the full period into two sub-periods; 1979-1992 and 1993-2003 and conduct their estimates separately. Empirically, they used a second order translog cost function based on national aggregate time series data using capital, energy and labor as inputs and real GDP as output. Their estimates of elasticities are significant and also greater than unity for both substitution and demand for energy. For example, their estimated MES (Morishima Elasticity of Substitution) is 1.406 for energy-capital and 1.133 for energy-labor during 1993-2003, implying that energy is significantly substitutable for both capital and labor. Meanwhile, demand for energy is also elastic, as energy consumption would increase by 12.3% if energy price is reduced by 10%.

Hang and Tu (2007) use a cost function to derive a linear demand regression function for coal, oil and electricity. Following Fisher-Vanden et al. (2004) and using a C-D cost function, they estimate a fuel demand function using the ratio of fuel to GDP as the dependent variables and use foreign direct investment and the price ratios of fuel price to output price as independent variables. They only estimate the elasticities of demand for individual fuel and aggregate energy. Their estimate of elasticity of demand for aggregate energy is -0.649.

Hu (2004) investigates the role of fuel prices in achieving substitution away from coal to alternative fuels at the industry level. He estimates a demand system of fuel shares (coal, oil, electricity, natural gas and petroleum) for four industries (chemical, metal, non-metal material and residential sectors) from 1990 to 2000. Several points can be raised about Hu's results. First, it may be misleading to discuss the substitution of oil and petroleum (defined as crude oil) in any industry because their functions are considerably different. Petroleum is not purely a fuel (directly used for power) but also an intermediate input to be used to produce fuel (such as gasoline, diesel, etc. Secondly, the estimated elasticities of both substitution and demand are extremely unstable over time, in particularly in 2000. For example, the estimated elasticity of substitution of coal-electricity is -1.88 in 2000, but they are minimal in the rest of years for the chemical industry. The same can be seen for elasticities of demand for coal. Thirdly, the elasticities of demand for coal are all positive for all four industries. Finally, the data used in this study are all indirect or derived which may partially explain the variation in estimated elasticities.

In addition, Liu, Liu and Pan (2007) observe the possibility of energy-labor substitution as well as the complementary of energy-capital during the last three years of the 1980s.

3.3.2 Some observations

a. First, it can be seen that there are only a few studies of China's energy demand and energy-other factor substitution. Guo and Wang (2005) and Guo (2005) state that the possibilities of substitution between energy and other factors has been ignored by Chinese scholars on energy economics. Even the effects of substitution between energy and other factors on energy consumption are often mistaken as a kind of technological progress in mainland China (Guo and Wang, 2005). It seems that Wei, Liao and Fan never mention any effects of factor substitution in their Chinese working papers and publications.[4] Likewise, it seems that Shi has not published results on the substitution of energy and other factors in her Chinese academic work.[5] As a result, it is not surprising that there haven't been any regional or industrial studies on energy demand and energy-other factor substitution.
b. When we do find some results in these areas the estimated substitution elasticities of energy and capital vary considerably and some are just unrealistic for example, the substitution elasticity of energy and capital of 2.5 reported by Zheng and Liu (2004b) while it is 0.69 in Huang and Huo (2006). Moreover, these elasticities are

[4] They stand for Center for Energy and Environmental Policy Research, Institute of Policy and Management, Chinese Academy of Sciences, Beijing, China, which is the first most important institute for the study of Chinese energy economics.

[5] She represents the Center for Energy Economics, Institute of China's Industry Economics, Chinese Academy of Social Sciences, Beijing, China, which is the second most important institute for the study of Chinese energy economics.

much larger than those estimated for South Korea (0.78), Portugal (0.89) and Germany (0.87) (see Table 6).

c. The reasons why these estimated elasticies of energy-capital substitution are so large and unstable has not been fully explained, however, there are several potential factors. Firstly, model specification appears important for example, there is no interaction term for energy price and output in Fan, Liao and Wei (2007). Secondly, sample periods seem short. There are only 13 observations in Fan, Liao and Wei (2007). Thirdly the difference between MES and AES. Fourthly, only national aggregate output and derived energy price indices are used in these studies.

d. In view of the above, new and more representative datasets and more appropriate robust econometric approaches are needed to explore the estimation of the elasticities of substitution of energy-capital and energy-labor and the demand for energy in the future for China. As suggested by Xing (2004) and Tong and Tong (2007), there is considerable work for researchers to do, especially to establish energy demand functions and estimate the possibilities of inter-factor and inter-fuel substitution.

e. To fill this gap, Ma et al. (2008) conduct a large scale investigation in this area. They estimate a third order translog cost function for China's economy. The datasets are new and appropriate as they are direct measures. The energy price data are spot prices for 30 provincial capital city markets collected by local governmental official. The energy consumption data come from the China Energy

Statistical Yearbook by industry and by province. The database comprises time series, cross-sectional disaggregated by industry and province.

3.4 Energy price convergence in China

3.5.1 The importance of energy price convergence

The ongoing transition of former communist countries from planned to market economies has been one of the most important economic phenomena in the last few decades. It is interesting, therefore, to consider whether the liberalization of domestic trade prompts major shifts in price structures that were highly distorted under central planning (Fan and Wei, 2006). Such a study is interesting because of the ongoing debate as to whether China's gradualist reform has been successful (see Lau, Qian and Roland, 2000; Young, 2000; Poncet, 2003 and 2005). Since China embarked on its economic reform and adopted an open door policy in the late 1970s, its economic development has been greatly enhanced by its active participation in international trade. However, recently there has been more debate about domestic trade and China's major trading partners have strongly urged it to further open its domestic market, especially after it has admitted to the World Trade Organization (WTO). However, even if the Chinese government removes the barriers to international trade, the effectiveness of this policy might be compromised by regional trade barriers within China itself (Fan and Wei, 2006). It is thus useful to test whether domestic markets are in fact integrated which can then provide some important information on how the market works in China (Zhou, Wan and Chen, 2000). Such information may help the government decide on the extent to which it should intervene in the market and how (Wyeth, 1992). As energy is one of the most important drivers of economic growth, energy price convergence is one of the important indicators for measuring market liberalization.

3.4.2 An area where less research has been undertaken

As can be seen from the last section, there are only a few studies focusing on China's energy demand and energy-other factor substitution. However, there has been even less research into China's energy price convergence, in fact only one piece of work Fan and Wei (2006),can be found on this topic. Fan and Wei (2006) report their tests for *The Law of One Price* using 72 time series (41 industrial products, 20 agricultural products, 13 other consumer goods and 18 service products). However, their study includes only two fuel variables (gasoline and diesel), which one might expect, *a priori* to be the most likely to show market integration among the key energy inputs.

3.4.3 More work needs to be done

To fill this gap, we report here some new results on energy price movements using a new, high frequency, dataset that consists of the market prices of four energy types (coal, electricity, gasoline and diesel) from 31 provincial (or autonomous regions and municipal) capital cities collected at 10-day intervals over a maximum of 132 months (from 1995 to 2005). We provide results for two key energy input prices, coal and electricity, whose price convergence has not yet been reported for China. Our conclusions are that the coal market is convergent as a whole in China, but the electricity market may not be integrated as a whole based on the existing electricity network and other relevant energy market factors (Ma, Oxley and Gibson, 2007).

3.5 The reforms to China's energy industry

The institutional reforms in China's energy industry comprise two aspects. The first is administrative or regulatory system reform; the second is energy pricing deregulation. Understanding energy reform is crucial to understand China's energy situation, therefore, this section reviews existing studies of energy. As most reforms to the energy industry took place in the 1990s, this section focuses on that period.

3.5.1 The reforms of the regulatory system

There are four articles that focus on regulatory system reform in China's energy industry. Andrews-Speed, Dow and Gao (2000) comprehensively introduce the ongoing reforms to the government and state sector in China's energy industries. Firstly, they describe the government structure pre- 1998 and then consider the structure after the 1998 reform. They then evaluate the new government structure And finally conclude that during the last 15 years countries across the world have initiated major programs of structural reform of their energy industries and China appears to be set to move down a similar path. The 1998 reforms were intended to reduce the cost of government, to separate the functions of government and enterprises, and ultimately, to increase the effectiveness of government. Their analysis suggests that the first two may have been achieved, but little progress has been made to the third objective.

Regulatory reform of the electricity industry is the toughest area in China as electricity is a 'staple' consumption good for residential and industry and its supply has typically been less demand for most periods of time in China. Therefore, regulatory reform of the electricity industry has attracted more attention and it has generated many studies. The most representative are, for example, Xu and Chen (2006), Cherni and

Kentish (2007) and Ma and He (2008), who have comprehensively described the regulatory reforms of China's electricity industry. According to the regulatory reforms, they distinguish historical regulatory changes into several sub-periods or stages in China.

Coal is the largest source of primary energy supply in China. However, coal is abundant and supply far exceeds demand in China. Reform of the regulatory system for coal industry was almost complete in the early 1990s. Andrews-Speed, Dow and Gao (2000) and Wang (2007) have discussed the regulatory reforms for China's coal industry. The only issue still to be reformed is the mediation system for coal that is sold to state-owned power generation sector. The articles above did not discuss the resolution of this as the China Taiyuan Coal Exchange (CTCE) was only established in June 2007 (CTCE, 2007.

Most of these articles on the regulatory reform in China's energy industry provide the detailed timetable of regulatory system reforms in addition to the main objectives and goals of regulatory reform to the petroleum industry. Andrews-Speed, Dow and Gao (2000) demonstrate that the relationship between policy formulation, regulation and enterprise management.

3.5.2 Price deregulation

The creation of a market-oriented pricing system is the basis of the government's price deregulation in the energy economy. As energy pricing plays an important role in energy consumption, energy efficiency and energy-environment relationship, many scholars have paid attention to the changes of pricing system in China's energy industry. Many researchers have deliberately addressed the historical changes of pricing deregulation and decentralization on China's energy demand for example, Wu (2003), Hang and Tu (2007), Wang (2007), and Cherni and Kentish (2007). Similar to regulatory reform, pricing reforms in China's energy industry have also been well documented and extensively described. Many articles not only carefully introduce initial pricing deregulation commenced in the early 1990s, but present ongoing pricing reforms.

3.5.3 Some observations and conclusions

There are several key points that can be drawn based on the above:

- The history of both regulatory system reform and pricing deregulation in China's energy industry has been well documented in the energy economics literature. The complete historical timetable of energy industry reforms have been provided by the existing studies.
- Some authors not only consider the future objectives and goals of the ongoing reform of China's energy industry, but also foreshadow the possible challenges and difficulties in the course of the development of China's energy economy (Xu and Chen, 2007). However, most of papers reviewed simply focus on a describing the reform programs.
- Although the existing articles consider all the policy reforms they do little other than describe them
- The existing literature does not consider why the progress of energy reforms has been so slow given that China has already had the three-decades of successful

reform in many other industries. There are many reasons, but the following might be the most important. Firstly governments may want business reform, but conditional on social stability and sustainable economic growth. More importantly, regulatory bodies did not have any academic support especially econometric based to evaluate the potential effects of each specific policy reform.

There are few papers that study the effects of energy policy reforms both on changes to energy intensity and the emergence of energy market in China. As reviewed previously few studies on energy intensity incorporate the effects of energy reforms on the changes in energy intensity. Likewise, few studies on energy reforms mention any effects of energy reforms on the changes in energy intensity and few studies on energy market integration incorporate energy reforms into the emergence of energy market. It is clear that the effects of energy reforms on the changes in energy intensity and the emergence of energy market in China have been generally ignored to date. All these topics deserve more exploration from researchers to provide evidence and advice for future policy making. In fact, for example, studies on the impact of utility restructuring on generation efficiency, environment, and social welfare have been extensively investigated in other countries for example, the U.S. (Ma and He, 2008).

4. The main findings on existing studies of China's energy economy

Firstly, the methods used to study China's energy consumption are typically simple time series analysis. Demand functions are seldom employed to model China's energy demand and predict energy consumption for example, it can be seen from table 5 that general decomposition indices are used to investigate China's energy intensity change and almost all of the studies take the view that industrial structural change is the key factor in aggregate energy intensity change. Real demand functions or models for China's energy consumption have rarely been used by existing studies. Most choose and estimate a simple C-D production function. Zheng and Liu (2004b) and Fan, Liao and Wei (2007) estimated a translog cost function, but their functional forms are also very simple versions of the translog function (without any second order interaction terms of input prices and output variables). Therefore, many econometric hypotheses cannot be tested (Ma et al. 2008).

Secondly, data used in previous studies are very limited and more data needs to be analyzed. Data availability is always a great challenge for researchers when they study China's energy economy. Rawski (2001) argues that official Chinese statistics contain major exaggerations of real output growth beginning in 1998 and the standard data contain numerous inconsistencies. Similarly, Sinton (2001) concludes that the available information suggests that while energy statistics were probably relatively good in the early 1990s, but their quality has declined since the mid-1990s, from which he suggests that China's energy statistics should be treated as a starting point for analysis and explicit judgments regarding ranges of uncertainty should accompany any firm conclusions. Even when faced with these issues, most of the studies still focus on and use national aggregated output and energy consumption data (Tables 4 and Table 5). On the other hand, existing research has not analyzed energy market price information as part of the study of China's energy demand and consumption predictions - the exception being a recent study by Ma et al. (2008). Most studies rely only on the time series analysis of two variables to predict China's economic growth and energy demand (e.g., Crompton and Wu, 2005; Chan and Lee, 1996). China's energy demand and consumption issues attracted little research in the traditional economic areas of estimates of price elasticities of demand for energy and substitution elasticities of energy-capital and energy-labor, etc., despite the fact that energy market price data have been available since the early 1990s (for most of energy fuel, such as coal, electricity, gasoline and diesel etc.). These data have are also disaggregated by urban and rural as well as regional market prices.

Thirdly, as can be seen from the papers reviewed, most data used are measured at the national, aggregate, level and few regional or provincial level disaggregate data are explored. Why does using regional disaggregate data matter? There are more than 30 provinces or regions in mainland China, many of which have their own special priority policies developed by central government. In addition, the variations in regional or provincial economic development in mainland China are extremely important and obvious. Using national aggregate information masks these differences across regions or provinces and is a particularly important issue when investigating China's market integration (Poncet, 2003 and 2005). However, most of the empirical papers use national aggregate data in their analyses of energy intensity change and economic growth and energy consumption cointegration relationship. Few studies are focused on regional or provincial level data analysis. Therefore, cross sectional economic growth and energy consumption data are seldom explored and utilized to investigate regional or provincial energy demand and consumption. Specially, cross sectional and time series fuel market price data are rarely used, excepts include Ma et al. (2008) and Fan and Wei (2006).

Fourthly, most studies treat the time series data as homogeneous. Few break China's economic development into different periods or stages which may explain why published conclusions often diverge. China's economic development was initiated by the Reforms in the late 1970s. Chinese economic development consists of a series of five-year plans. Each five-year plan period has its special goal (e.g., growth rate) and each of them may have special policy measures. Within a short time period, they may exist a similar policy environment, but over longer periods the policy scenarios may vary. This is particularly true when using long-run time series analysis estimating the relationship between energy consumption and economic growth. As reviewed previously, some studies actually treat the policy environment before and after the reform as the same. As a result, the long-run cointegration relations derived from the same model differ in their estimates and conclusions.

Fifthly, some production functions have been estimated, but production assumptions and market integration assumptions have not been rigorously tested. Factor market integration and cointegration are one of the most sensitive issues related to China's membership of the WTO. The testing of various commodity market hypotheses have attracted both Chinese and foreign research (e.g., Young, 2000; Fan and Wei, 2006; Poncet, 2003 and 2005), the exception has been the energy market. Although energy has been identified as one of the most important input factors (Berndt and Wood, 1975), China's energy input factor market integration has not been investigated with the exception of a few recent papers. Fan and Wei (2006) use a unit root test to investigate gasoline and diesel market integration across 35 Chinese cities. Warell (2006) incorporates the Chinese coal market into international perspective. Gnansounou and Dong (2004) investigate the opportunity for inter-regional integration of electricity markets. However, it is hard to conclude that China's energy market is well integrated as a whole based on those studies. Ma, Oxley and Gibson (2007) do conduct a series of tests for energy price convergence for energy spot prices of four major fuels at 30 provincial capital cities all over the country. Their tests and results show that oil and coal markets in mainland China are integrated as a whole, but it is hard to say that the electricity market is also integrated as a whole based on the available information on electricity networks. Sixthly, the reasons why energy intensity has changed should have been more carefully investigated. As reviewed previously, many studies that have addressed China's energy intensity, however, all of them consider only a changing industrial structure and individual industrial energy efficiency improvement as the reasons. What is clear, however, is that that do little more than explain how a measure of energy intensity is actually created, normally, by some form of decomposition index approach. It is clear that aggregate energy intensity is a weighted average of individual industrial energy intensities using industrial structure as a weight. More economic analysis is required as to why change occurs including the role of technological change, income growth and factor substitution which, with the exception of for a recent study by Ma et al. (2008), have not been addressed

Finally, as official energy data are not transparent, China's energy economy studies are limited to very narrow fields. It seems strange to talk about 18 Asian country's energy consumption and economic growth without China. However, many Asian energy economy studies exclude China (see Liu and Ang 2003).

5. Some policy implications

Based on the papers reviewed and some of the concerns raised in this review or implied by the authors, we propose a number of issues and solutions that would encourage and support future work on China's energy economy:

1. Make energy production and consumption statistics more transparent, regular and available. Unlike other countries (e.g., US, Turkey, Germany, South Korea, etc), China's energy economics is less well developed. The reasons are mixed, but energy data availability is one of the most important constraints.
2. Allow the free downloading of official energy economic data and international participation in the investigation of China's energy economics.. General production and consumption data should be made publicly available so that researchers can easily locate and download them to encourage and support the study of China's energy economy.

   Encourage researchers both domestic and overseas to participate in the study of China's energy sector. Wang, Wang and Zhao (2008) review the literature on energy saving and the opinion of experts from the energy industry and academia and find 13 main barriers to energy saving in China. Two barriers to energy saving are identified as inadequate data and information and public participation.

6. Some areas for potential future study

According to the main findings noted above and comparisons between China and other countries there are a few areas that might merit future attention:

1. Factor substitution in energy the economy needs more attention and more research effort. There is only one paper focusing on China's energy and other factors substitution, and that study is incomplete as the translog cost function definition excludes the interaction term for input and output variables due to data constraints. Also it seems that the importance of the substitution between energy-capital and energy-labor is not well appreciated by both the Chinese and English literatures as there appears to be only one English paper published on this issue. Therefore, it might be concluded that the study of China's energy economics, especially the demand side, is far behind that of other countries.
2. Energy market integration is also an underdeveloped area. Firstly, with rapid economic income growth, energy consumption has been increasing and therefore, the study of energy economics has become more important. Secondly, none of the Chinese articles on China's energy economics have been found which investigates China's energy market integration. Thirdly, even the English literature on Chinese energy economics comprises only one paper focused on China's market integration, covering only two fuels (gasoline and diesel). In addition, a study of energy integration is an important part of an investigation of national market integration in China, especially after China's re-accession to the WTO.
3. The study of regional or provincial energy economics is worthy of more attention. Several points arise here: Firstly, interregional variation in economic growth and

other aspects are apparent in China, which may be larger than between China and some of its other trading partners. Secondly, China's energy market integration debate should pay attention to regional energy market integration rather than consider simple national aggregate time series, co-integration and causality analysis. Thirdly, more attention should be paid to regional factor substitution in the study of energy economics as there is substantial variation in regional industrial structure and economic development as well as idiosyncratic regional policy priorities.

4. Economic growth and energy consumption relationships have been investigated both intensively and extensively. However, most of the existing studies confuse or ignore different phases of China's economic development and are less likely to reach a consensus as a result. Therefore, conducting any long-run economic relationship needs to realize and test for changing policy environments first and then break into various different periods as necessary. This also applies to both the study of national and regional energy economics

5. Energy market price data have never been explored when studying China's energy economics. Fan, Liao and Wei (2007) complain that there are many problems with China's data, such as inconsistency and omissions, however, most major fuel market price datasets have been available since 1995 (some even earlier, for example, coal and diesel have been available since the late 1980s). It is interesting to note that many energy economics studies have tried to predict China's future energy demand and consumption, but none of them have used energy market price

information to establish energy demand function and to estimate elasticities of demand for energy (as well as factor substitution).[6] As a consequence it may not be a surprise, therefore, that there are significant differences among the published predictions of China's future energy demand (Crompton and Wu, 2005). Based on the papers herein reviewed, it seems clear that China's energy price data availability has impacted researchers' ability to conduct a comprehensive study of China's energy economics.

6. The effects of energy reforms should be considered. Specific topics might include studies of: i) the potential effects of energy reforms on the changes in energy intensity, ii) the effects of energy reforms on the emergence of energy market; iii) the potential effects of energy reforms on energy supply and demand; and iv) the effects of energy reforms on social stability, social welfare, environment, and sustainable economic growth.

[6] Fan and Wei (2006) touched China's energy market price data (but, they are only gasoline and diesel spot prices) when they demonstrate the one law of the price for transitional economy of China.

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Table 1. Raw coal roles in China's energy demand and supply, 1978-2006, %

Year	Share of raw coal in primary energy consumption	Share of raw coal in primary energy production	Share of electricity generated from coal
1978	70.7	70.3	-
1980	72.2	69.4	80.6
1985	75.8	72.8	77.5
1990	76.2	74.2	79.6
1991	76.1	74.1	80.1
1992	75.7	74.3	81.2
1993	74.7	74.0	81.6
1994	75.0	74.6	80.4
1995	74.6	75.3	79.8
1996	74.7	75.2	81.3
1997	71.7	74.1	81.5
1998	69.6	71.9	81.0
1999	69.1	72.6	82.3
2000	67.8	72.0	82.2
2001	66.7	71.8	80.0
2002	66.3	72.3	80.9
2003	68.4	75.1	82.7
2004	68.0	76.0	81.5
2005	69.1	76.5	81.9
2006	69.4	76.7	82.7

Data source: calculated based on China Statistical Yearbooks, 1996-2007.

Table 2. List of studies on Asian energy economy that exclude China

Author(s)	Topic	Asian or Developing countries covered (# of countries)
Mahadevan and Asafu-Adjaye (2007)	Energy consumption, economic growth and prices: a reassessment using panel VECM for developed and developing countries	Argentina, Indonesia, Kuwait, Malaysia, Nigeria, Saudi Arabia, Venezuela, Ghana, India, Senegal, South Africa, South Korea, Singapore and Thailand (14).
Lee and Chang (2007)	Energy consumption and GDP revisited: A panel analysis of developed and developing countries	Argentina, Chile, Colombia, Ghana, India, Indonesia, Kenya, Malaysia, Mexico, Nigeria, Pakistan, Peru, Philippines, Singapore, Sri Lanka, Thailand, Turkey and Venezuela (18)
Sari and Soytas (2007)	The growth of income and energy consumption in six developing countries	Indonesia, Iran, Malaysia, Pakistan, Singapore and Tunisia (6).
Lee (2005)	Energy consumption and GDP in developing countries	South Korea, Singapore, Hungary, Argentina, Chile, Colombia, Mexico, Peru, Venezuela, Indonesia, Malaysia, Philippines, Thailand, India, Pakistan, Sri Lanka, Ghana and Kenya (18).
Asafu-Adjaye (2000)	The relationship between energy consumption, energy prices and economic growth: time series evidence from Asian developing countries	India, Indonesia, the Philippines and Thailand (4).
Murry and Gehuang (1994)	A definition of the gross domestic product – electrification interrelationship	India, Philippines, Zambia, Colombia, El Salvador, Indonesia, Kenya, Mexico, Canada, Hong Kong, Pakistan, Singapore, Turkey, Malaysia and South Korea (15).

Table 3. The papers reviewed: China’s economic growth and energy consumption

Author (s)	Papers reviewed
Zhao and Fan (2007)	Zhao & Wei (1998), Lin (2003a, b), Han et al. (2004) and Ma et al. (2004)
Liu, Ceng and Liu (2006)	Chen et al (1996), Zhao & Wei (1998), Wan et al. (2000), Zhu (2002), Han et al. (2004), Zhang & Li (2004), Zhou (2004), Li (2005), Wu et al. (2005), and Yang (2005)
Liu (2007)	Zhao & Wei (1998), Lin (2001), Ma et al. (2004), Fan & Zhang (2005), Ni and Ling (2005), and Wang et al. (2005)
Guo (2007)	Zhao & Wei (1998), Lin (2003b), Ma et al. (2004), Fan & Zhang (2005) and Ma & Zhang (2005) and Wu et al. (2005).
Wang and Yang (2006)	Jiang (2004), Lin (2004), Wang et al. (2005), and Wu et al. (2005)

Table 4-1. Existing studies on the relationship between national aggregate energy consumption and aggregate economic growth in China

Author(s)	Period	Approaches	ECM Coeff. (t-statistics)	Granger Causality
Zhao and Fan (2007)	1953-1976	STR	-	Energy →GDP
Chan and Lee (1996)	1953-1993	JJ, ECM	-0.76**	Energy →GDP
Lin (2001)	1953-1994	JJ, ECM	-0.70 (7.7)	LRC, 0.88 [a] (38)
Ma, Wang, He & Li (2004)	1954-2002	E-G, ECM	-0.05 (2.3)	Bi-directal.
Wang, Tian and Jin (2006)	1953-2002	TVP, Granger	-	Not fixed but vary
Zhang and Li (2004)	1961-2001	Granger	-	GDP→ Energy
Yuan et al. (2008) in Press	1963-2005	JJ, ECM	GDP→ Energy	Bi-directal.
Guo (2007)	1965-2004	JJ, ECM	-0.23 (2.1)	LRC, -1.06 [a] (2.9)[b]
Lee and Chang (2008)	1971-2002	ECM, FMOLS	-	Energy →GDP
Han et al. (2004)	1978-2000	E-G, ECM	-	Bi-directal.
Fan and Zhang (2005)	1978-2002	Granger	-	GDP→ Energy
Wu, Cheng & Wang (2005)	1979-2002	E-G	-	GDP→ Energy
Wang and Yao (2007)	1978-2003	ECM	Not exist	GDP→ Energy
Zhao and Fan (2007)	1977-2005	STR	-	Energy →GDP
Wang and Liu (2007)	1978-2005	E-G, ECM	<0	Energy →GDP
Wang and Yang (2007)	1978-2005	E-G, ECM	-0.39 (-3.3)	GDP→ Energy
Lei, Yang and Wang (2007)	1985-2001	C-D production	-	LRC, 0.06 [a]
Liu (2006)	1985-2003	Granger, ECM	-	GDP→ Energy
Huang and He (2006)	1985-2003	C-D production	-	Energy →GDP
Liu, Ceng and Liu (2006)	1985-2003	C-D production	-	LRC, 0.28 [a]
Liu, Ceng and Liu (2006)	1989-2003	C-D production	-	LRC, 0.14 [a]
Liu, Liu and Pan (2007)	1988-2005	GFEVD, GIR	-	GDP→ Energy
Ma and Zhang (2005)	1990-2001	Grey Linkage	-	LRC, 0.67 [c]
Ma, Wang, He & Li (2006)	1995-2003	Grey Linkage	-	LRC, 0.5-0.8 [c]
Yang, Tian and Ding (2004)	-	LEGM	-	-
Shao and Jia (2006)	-	Descriptive	-	-
Wan, Zhou and Gao (2000)	1957-1997	Descriptive	-	-

Note: STR is smooth transfer regression; JJ is Johansen-Juselius cointegration; ECM is error correction model; TVP is time varying parameter approach; FMOLS is fully modified OLS; E-G is Engle and Granger; GFEVD is generalized forecasting error variance decomposition; GIR is generalized impulse response; LEGM is Lucas economic growth model; LRC is long-run cointegration.

[a] elasticity of energy input; [b] including technological factor; [c] grey linkage coefficient.

Table 4-2. Existing studies on the relationship between disaggregate or aggregate economic growth and disaggregate energy consumption

Author(s)	Period	Approaches	ECM (t-stat)	Granger Causality
1. National trade and national aggregate energy consumption:				
Dong and Du (2007)	1978-2004	C-D production	-	LRC, 1.09 [a]
2. National economic growth and national coal consumption:				
Yuan et al (2008) in Press	1963-2005	JJ, ECM	GDP→ Coal	Bi-directal.
Wang and Yang (2007)	1978-2005	E-G, ECM	-	GDP →Coal
Zhang and Li (2007)	1980-2004	Granger	-	Bi-directal.
3. National economic growth and national petroleum consumption:				
Liu (2007)	1953-2004	E-G, Granger	-	Independent
Ni and Ling (2005)	1977-2002	ECM	-0.76	LRC, 0.68 [a]
4. National economic growth and national oil consumption:				
Zou and Chau (2006)	1953-2002	JJ, ECM	-	Energy →GDP
	1953-1984	JJ, ECM	-0.42 (2.3)	Bi-directal.
	1985-2002	JJ, ECM	-1.14 (2.1)	Bi-directal.
Yuan et al (2008) in Press	1963-2005	JJ, ECM	Bi-direct.	Bi-directal.
5. National economic growth and national electricity consumption:				
	1950-1980	C-D function	-	LRC, 2.72 [b] (12.0)
Huang (1993a)	1950-1970	C-D function	-	LRC, 3.52 [b] (7.0)
	1970-1980	C-D function	-	LRC, 1.56 [b] (15.0)
Shiu and Lam (2007)	1971-2000	E-G, ECM	-	Energy →GDP
Lin (2003a,b)	1978-2001	JJ, ECM	-0.43 (-3.1)	LRC, 0.86 [b]
	1952-2001	JJ, ECM		LRC, 0.78 [b]
Wang, Tian & Jin (2005)	1952-2002	E-G, ECM	-0.65 (-2.6)	Bi-directal.
Yuan et al (2008) in Press	1963-2005	JJ, ECM	Elect→GDP	Bi-directal.
Chen, Ma & Qin (2007)	1949-2004	Hsiao Granger	-	Bi-directal.
Yuan et al. (2007)	1978-2004	ECM, Hodrick-Prescott filter	-	Bi-directal.
6. Provincial aggregate economic growth and energy consumption:				
Tang and Croix (1993)	1952-1989	Panel data	-	LRC, 0.94 [b] (7.8)
Shandong trade and aggregate energy consumption:				
Zhu (2007)	1978-2004	E-G, ECM	0.41(5.0)	Bi-directal.

Note: JJ is Johansen-Juselius cointegration; E-G is Engle and Granger; ECM is error correction model; LRC is long-run cointegration.

[a] elasticity of energy input; [b] elasticity of income (per capita GDP).

Table 4-3. Empirical estimates of the relationship between industry aggregate energy consumption and aggregate economic growth for China

Industry	Reliability on energy(α_i)	Income elasticity of energy demand (β_{1i})	Efficiency elasticity of energy demand (β_{2i})
	Long term cointegration		
Food, beverage and tobacco	2.57 (5.6) [a]	0.81 (11.9)	-3.01 (-9.6)
Textile industry	3.83 (3.6)	0.65 (3.9)	-4.59 (-4.2)
Papermaking & paper products	3.94 (11.5)	0.72 (9.9)	-11.71 (-6.5)
Electricity, steam and water	2.86 (3.9)	1.11 (10.4)	-26.7 (-7.3)
Petroleum processing & coking	8.80 (9.2)	0.11 (0.7)	-31.40 (-12.7)
Chemical	4.31 (14.8)	0.82 (17.2)	-25.13 (-11.6)
Medical and pharmaceutical	1.66 (4.7)	0.96 (13.7)	-3.88 (-10.1)
Chemical fibres	3.30 (19.4)	0.78 (25.8)	-9.99 (-8.8)
Nonmetal mineral products	6.03 (15.1)	0.58 (7.9)	-23.63 (-5.9)
Ferrous metals processing	4.24 (9.3)	0.89 (13.2)	-41.62 (-6.7)
Nonferrous metals processing	2.76 (7.8)	1.01 (15.5)	-26.65 (-6.5)
Machinery & electric equipment	6.29 (15.1)	0.29 (5.1)	-0.76 (-3.9)

Industry	Elasticity of GDP growth	Elasticity of energy efficiency	Error correction coefficient
	Short term dynamic adjustment		
Food, beverage and tobacco	0.58 (-4.2)	-2.69 (-5.7)	-0.41 (-1.4)
Textile industry	0.77 (-2.6)	-6.11 (-3.3)	-0.99 (-2.0)
Papermaking & paper products	0.93 (-3.9)	-16.06 (-6.1)	-0.76 (-2.7)
Electricity, steam and water	0.37 (-0.5)	-29.34 (-12.4)	-0.72 (-3.1)
Petroleum processing & coking	0.57 (-2.4)	-29.21 (-10.2)	-0.79 (-3.3)
Chemical	1.21 (-9.6)	-41.95 (-13.9)	-1.14 (-5.7)
Medical and pharmaceutical	0.79 (-3.4)	-5.47 (-9.5)	-0.83 (-4.4)
Chemical fibers	1.01 (-6.0)	-12.61 (-13.1)	-1.08 (-4.1)
Nonmetal mineral products	0.85 (-3.5)	-37.56 (-4.6)	-1.08 (-2.2)
Ferrous metals processing	0.98 (-4.9)	-49.60 (-7.1)	-0.75 (-3.4)
Nonferrous metals processing	1.12 (-1.9)	-30.32 (-4.3)	-0.80 (-1.8)
Machinery & electric equipment	0.85 (-2.2)	-1.13 (-2.9)	-0.91 (-2.4)

Note: panel cointegration: $y_{it} = \alpha_1 + \beta_{1i} \mathrm{x}_{\mathrm{it}} + \beta_{2i} z_{it} + \upsilon_{it}$, where y and x are natural logarithm energy demand and output, z is energy efficiency (e.g., X/Y), β_{1i} is the income elasticity of the energy demand, α_i measures industrial static reliability on energy, β_{2i} measures the effect of change of energy efficiency on energy demand, and υ_{it} measures the effect of other factors on energy demand.

[a] The numbers in parenthesis are t-statistics.

Source: reported by Wang and Yang (2006).

Table 5. Contribution (%) of determinants to total energy intensity from various version of index decomposition for China

Author(s)	Economy	Period	Approach	Contribution to change in energy intensity (%)		Note
				Industrial intensity	Industrial structure	
Smil (1988)	Aggregate	1979-1987	-	-50	-50	-
Huang (1993b)	Industry	1980-1988	Divisia index	≈-87	≈-13	GOV
Chen (2007)	Industry	1998-2003	General index	-87	-13	-
Qi, Chen & Wu (2007a)	Light and heavy industry	1995-2000	Laspreyres	-111	11	Modified
Qi, Chen & Wu (2007a)	Light and heavy industry	2000-2005	Laspreyres	-108	8	-
Han, Wei & Fan (2004)	3 industries	1981-1990	General index	-25	-75	-
Han, Wei & Fan (2004)	3 industries	1981-2000	General index	-87	-13	-
Han, Wei & Fan (2004)	3 industries	1991-2000	General index	-125	25	-
Ding et al. (2007)	3 industries	1994-2005	General index	-102	2	substitute
Kambara (1992)	3 industries, 5 subsectors	1980-1990	Descriptive	≈-30	≈-70	-
Sun (1998)	3 industries, 6 subsectors	1980-1994	*Laspeyres*	-124	24	Modified
Qi and Chen (2006)	3 industries, 6 subsectors	1996-2001	Laspreyres	-114	14	Modified
Gao & Wang (2007)	3 industries, 6 subsectors	1996-2001	LMDI	-113	13	Estimated
Qi and Chen (2006)	3 industries, 6 subsectors	2002-2003	Laspreyres	42	58	Modified
Gao & Wang (2007)	3 industries, 6 subsectors	2002-2005	LMDI	70	30	-
Ma and Stern (2008)	3 industries, 34 subsectors	1997-2002	LMDI	-105	5	-
Ma and Stern (2008)	3 industries, 34 subsectors	1994-2003	LMDI	-110	-10	-
Ma and Stern (2008)	3 industries, 34 subsectors	2002-2003	LMDI	46	54	-

Peng & Zhang (2007)	5 industrial subsectors	1995-2003	Laspreyres	-125	25	estimated
Zhou and Li (2006)	6 industrial subsectors	1981-1990	Divisia indices	-40	-60	-
Zhou and Li (2006)	6 industrial subsectors	1991-2001	Divisia indices	-114	14	-
Zhang & Ding (2007)	6 industrial subsectors	1994-2001	General index	-112	12	Modified
Shi, Fu (2007)	6 industrial subsectors	1995-2000	Laspreyres	-111	11	-
Zhang & Ding (2007)	6 industrial subsectors	2001-2003	General index	20	80	Modified
Zhou and Li (2006)	6 industrial subsectors	2002-2003	Divisia indices	55	45	-
Shi, Fu (2007)	6 industrial subsectors	2000-2005	Laspreyres	69	31	-
Hu (2007)	13 industrial subsectors	1987-1997	IOSDA	-99	-1	-
Lin and Polenske (1995)	18 industrial subsectors	1981-1987	IOSDA	≈ -100	≈0	Lin (1996)
Garbaccio et al (1999)	29 industrial subsectors	1987-1992	IOSDA	< -100	>0	-
Zhang (2003)	29 industrial subsectors	1991-1999	ALI	-82	-18	-
Zha, Zhou & Ding (2007)	36 industrial subsectors	1993-2003	AMDI	-90	-10	-
Liao, Fan and Wei (2007)	36 industrial sbusectors	1997-2002	Törnqvist index	-106	6	-
Fisher-Vanden et al (2004)	National firm level	1997-1999	MAMD	-47	-53	-
Sinton and Levine (1994)	11-49 industrial subsectors	1985-1990	*Laspeyres*	-90	-10	GOV
Yu (2007)	3 industries, 5 subsectors	1990-1995	General index	-120	20	Guangdong
Yu (2007)	3 industries, 5 subsectors	1995-2005	General index	-103	3	Guangdong

Note: Aggregate energy intensity increases if total contribution is positive and vice versa.
MAMD: Multiplicative arithmetic mean Divisia indices; AMDI: arithmetic mean Divisia indices; LMDI: logarithmic mean Divisia indices; IOSDA: Input-output techniques - structural decomposition analysis; ALI: additive Laspeyres index; GOV: gross output value.

Three industries are: i) The primary industry, including only agriculture and related activities (farming, forestry, husbandry, secondary production and fishing); ii) Secondary industry, includes mining, manufacturing, water supply, electricity generation and supply, steam, the hot-water and gas sectors, and construction; iii) Tertiary industry, including transportation (including postal and telecommunications services), commerce and others.

Table 6. International comparison of the elasticities of substitution of energy-other factors and the elasticities of energy demand

Author(s)	Country	Economy	Period	Function, factors included	σ_{EK}	σ_{EL}	η_{EE}
Qian and Wang (2003)	China	National	1979-2000	C-D production, EKL, T	-	-	-0.110
			1993-2000		-	-0.863	-0.399
			1979-1992		-	0.117	-0.311
Zheng and Liu (2004a)	China	National	1978-2000	CES and C-D production, EKL, T	1.000	∞	-
Zheng and Liu (2004b)	China	National	1978-2000	Translog production, EKL, T, no time variable	2.500	0.500	-
Huang and Huo (2006)	China	National	1985-2003	Second order CES production, EKL, T	0.685	-	-
Fan, Liao and Wei (2007) [a]	China	National	1993-2003	Translog cost, EKL, T	1.406*	1.133*	-1.234*
			1979-1992	No interact terms of price-output	-0.369*	-0.447*	0.308*
Hang and Tu (2007)	China	National	1985-2004	Linear fuel demand regression, T	-	-	-0.649
Cho, Nam and Pagan (2004)	South Korea	National	1981-1997	Translog cost, EKL, T	0.783	-1.418	0.356
Welsch and Ochsen (2005)	West Germany	Production sector	1976-1994	Translog cost, EKLM, T	-0.399	-0.075	-
Christopoulos (2000)	Greek	Manufacturing	1970-1990	Translog cost, EKL, T	0.250	0.050	-
Vega-Cervera and Medina (2000)	Portugal	National	1980-1996	Translog cost, EKL, T	0.893	0.812	-0.689
Vega-Cervera and Medina (2000)	Spain	National	1980-1996	Translog cost, EKL, T	-0.012	0.300	-0.122
Kemfert and Welsch (2000)	Germany	Entire industry	1970-1988	CES production, EKL, T	0.871	0.167	-
Frondel (2004)	U.S.A.	Manufacturing	1947-1971	Translog cost, EKLM, T	-3.88	0.660	-
Berndt and Wood (1975)	U.S.A.	Manufacturing	1947-1971	Translog cost, EKLM, T	-3.246	0.644	-0.474
Berndt and Wood (1979)	U.S.A.	Manufacturing	1947-1971	Translog cost, EKLM, T	0.120 [b]	-	-

Note: E stands for energy; K stands for capital; L stands for labor, and M stands for materials. T stands for time series data and TS stands for panel data. σ_{EK} and σ_{EL} are the elasticities (AES) of energy-capital and energy-labor. η_{EE} is elasticity of demand for energy.

[a] Morishima elasticity of substitution (MES); [b] in 1971.

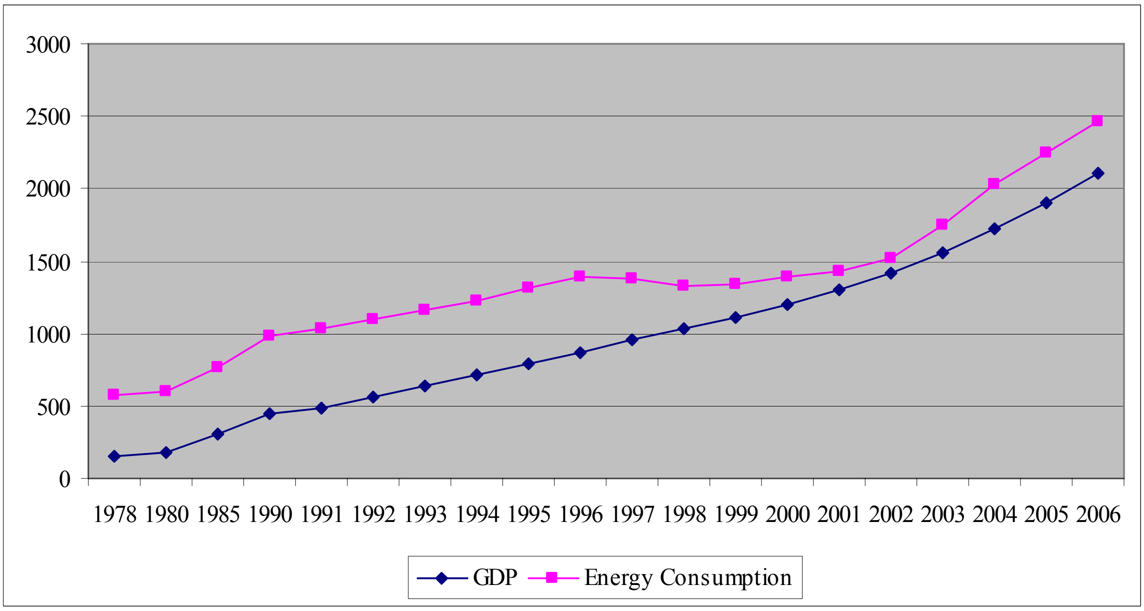

Figure 1. China's GDP and aggregate energy consumption, 1978-2006
Note: GDP is measured in 10 billion Chinese yuan based on the 2006 price. Aggregate energy consumption is measured in million ton standard coal.
Data source: China Statistical Yearbooks.

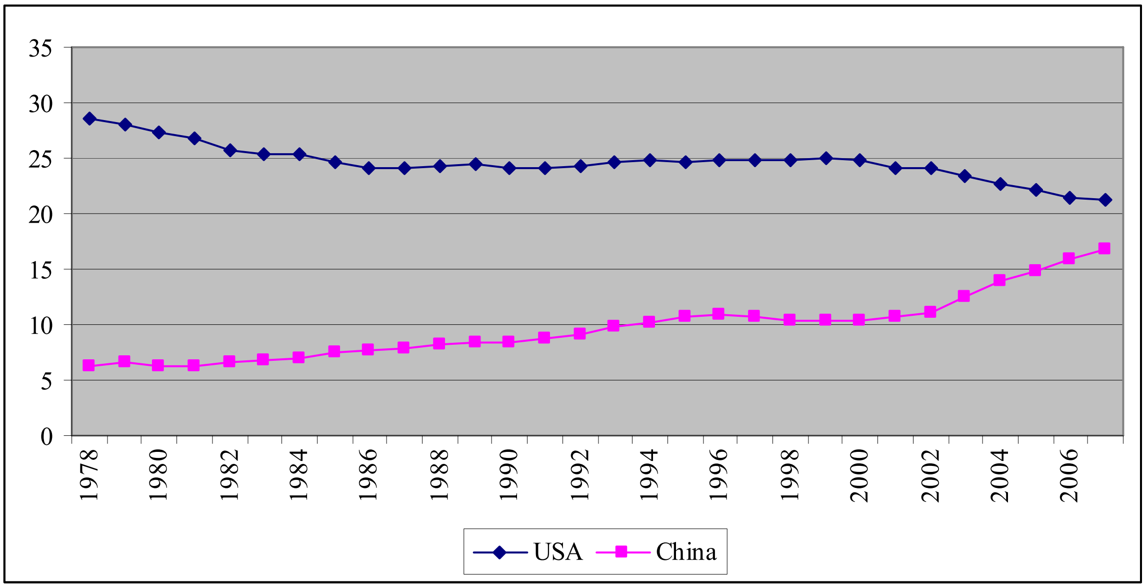

Figure 2. Comparison of global share of primary energy consumption between China and USA, 1978-2007
Data source: BP Statistical Review of World Energy June 2008.

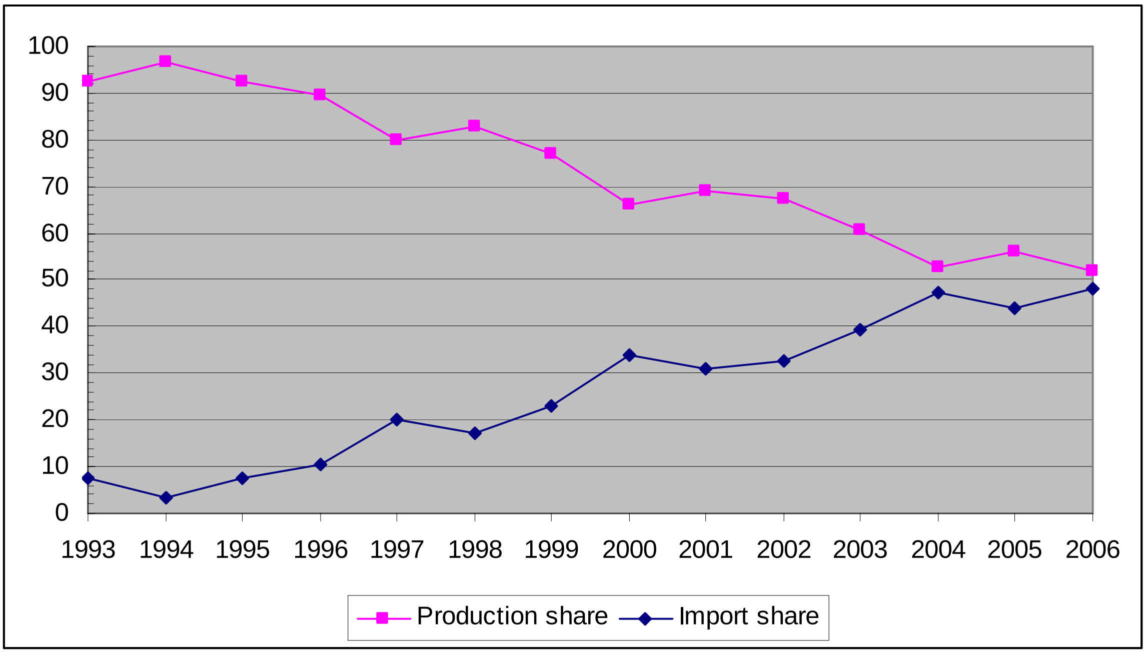

Figure 3. Petroleum and product shares of China's domestic production and import in aggregate oil consumption, 1993-2006
Data source: China Statistical Yearbooks, 1994-2007.

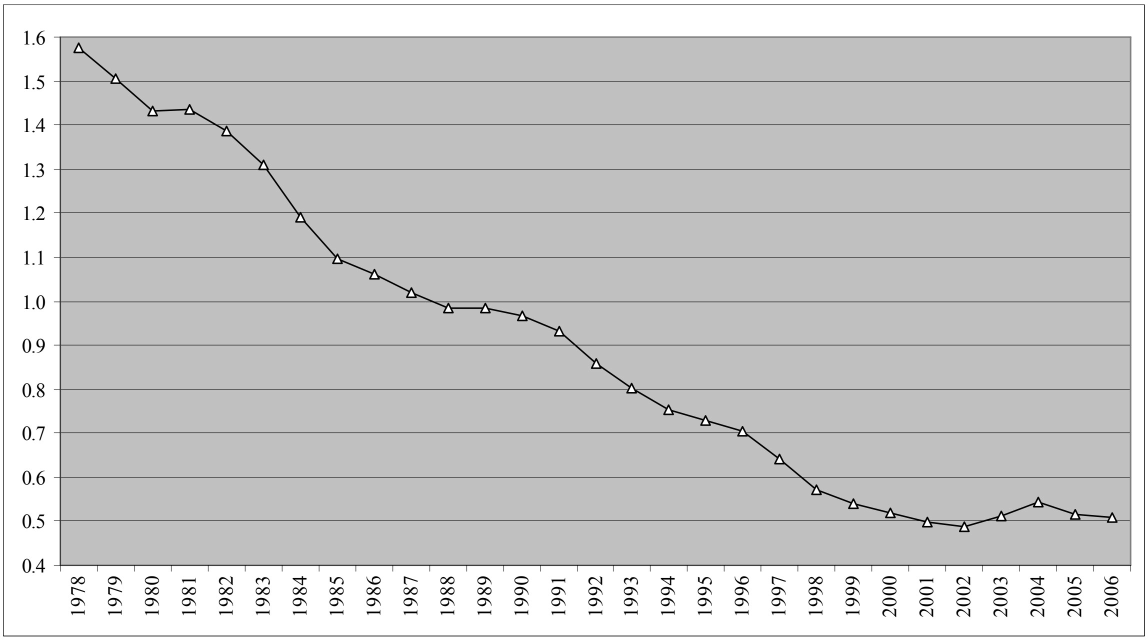

Figure 4. Energy intensity (ton/1000 RMB) measured by the ratio of aggregate energy consumption (million ton standard coal) to GDP (billion RMB in 1978 price).

Data source: China Statistical Yearbooks, 1994-2007