Economic Systems 34 (2010) 105–132

Contents lists available at ScienceDirect

Economic Systems

journal homepage: www.elsevier.com/locate/ecosys

China's energy economy: A survey of the literature

Hengyun Ma [a,b,*], Les Oxley [b], John Gibson [c]

[a] College of Economics and Management, Henan Agricultural University, 95 Wenhua, Road, Zhengzhou 450002, China
[b] Department of Economics, University of Canterbury, Private bag 4800, Christchurch, 8140, New Zealand
[c] Department of Economics, University of Waikato, Private Bag 3105, Hamilton, New Zealand

ARTICLE INFO

Article history:
Received 27 March 2009
Received in revised form 9 December 2009
Accepted 11 December 2009

JEL classification:
D24
O33
Q41

Keywords:
China
Energy
Literature review

ABSTRACT

This paper reviews the literature on China's energy economy, focusing particularly on: (i) the relationship between energy consumption and economic growth; (ii) China's changing energy intensity; (iii) energy demand and energy-non-energy substitution; (iv) the emergence of energy markets in China; and (v) economic reforms in the energy industry. After reviewing the literature, the paper presents the main findings that some important issues remain unanswered, for example, what determines energy consumption behavior; the effects of substitution of and demand for energy; and technological change effects on energy intensity. Finally, the review suggests some topics worthy of future study.

1. Introduction

China is one of the largest and fastest growing emerging economies whose performance has been supported by the reforms of the late 1980s. According to the National Bureau of Statistics of China (2009), its GDP growth rate has approximated 10% annually and its aggregate GDP reached 4.33 trillion US dollars by 2008. Correspondingly, China's energy consumption also expanded both in volume and growth rate terms during the same period, especially post-2002. China's primary energy consumption reached 2002.5 million tonnes oil equivalent in 2008, with the annual growth rate being as high as 16.8% for the period 2002–2008 (BP, 2009). As a result, China has become the second largest

* Corresponding author. Tel.: +86 371 63579691; fax: +86 371 63555638.
E-mail address: h.y.ma@163.com (H. Ma).

0939-3625/$ – see front matter
doi:10.1016/j.ecosys.2009.12.001

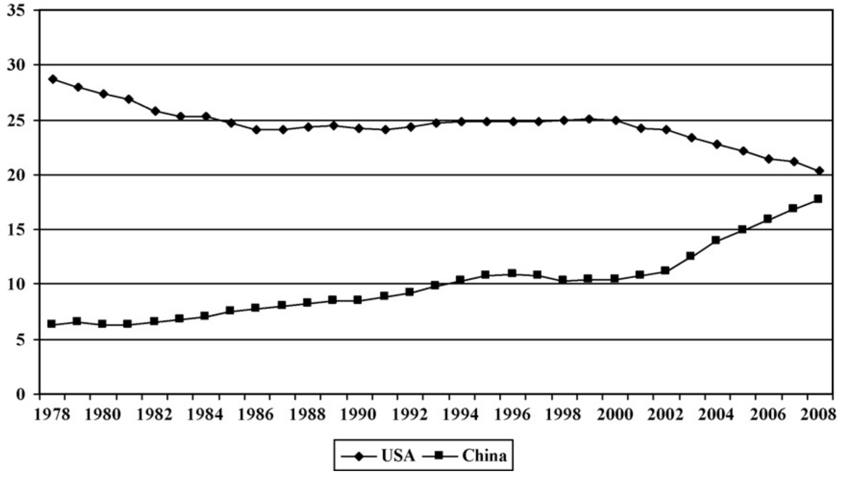

Fig. 1. Comparisons of global share of primary energy consumption between China and USA, 1978–2008.*Data source*: BP Statistical Review of World Energy June 2009.

consumer of energy products after the USA and its global shares of primary energy consumption have increased dramatically since 1978. 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 soared to 17.7% in 2008 while the USA's global share decreased dramatically to 20.4% in 2008 (Fig. 1).

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 53% in 2008 (Fig. 2). By 2008, China's imports of crude oil and products reached 217.8 million tonnes, becoming the third largest importer after USA and Japan (BP, 2009).

However, China's energy economy is less developed and less fully understood in an international sense compared with its global importance. Despite some areas having been extensively investigated, for example the relationship between energy consumption and economic growth, changes in energy

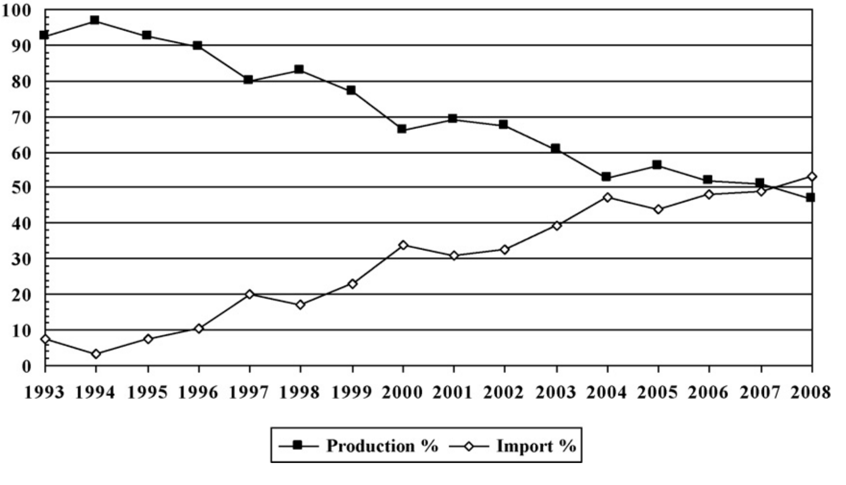

Fig. 2. The shares of domestic production and import in aggregate petroleum and product consumption in China, 1993–2008.*Data source*: National Bureau of Statistics of China, 1994–2009, and BP (2009).

Table 1
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)

intensity, and many other important issues, including energy price convergence, energy demand, energy-other factor substitution, and energy studies at the disaggregate level, have not been extensively studied or, in some cases, considered at all. More interestingly, many empirical studies of Asian or developing country's energy economies exclude China from their analysis (refer to Table 1 for details).

Energy policy reforms have played an important role in the development of China's energy economy and, as a consequence, there are many studies that relate to China's energy reforms (Andrews-Speed et al., 2000; Xu and Chen, 2006; Cherni and Kentish, 2007; Ma and He, 2008; Wu, 2003; Wang, 2007; Hang and Tu, 2007). All these studies, however, simply introduce and describe the institutional reforms as they relate to China's energy sector, rather than considering their potential effects on the development of the sector or economic growth more generally.

Given the importance and rapid pace of economic growth and changes to the energy sector, there is 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 to date on the energy sector, will inform both academic and political decision making including, crucially, that relating to the energy sector and 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 of future energy demand, imports and, crucially, impacts on economic growth, employment and, increasingly, the environment. 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.

This review is organized as follows. Section 2 outlines the main topics to be reviewed and the approaches used. 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 4 presents a summary of the main findings and Section 5 provides some policy implications. The final Section 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. However, a single review paper cannot address all these elements, therefore we 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 an energy market in China, and (v) policy reforms in the energy sector. The reasons we have chosen these five topics are, firstly, that most of the existing energy economics literature covers them. Secondly, most of the papers published in energy economic journals (for example, *Energy Economics, Energy Policy, The Energy Journal*, *Renewable and Sustainable Energy Reviews*) predominantly include these topics. Thirdly, they are five of the most popular and most extensively investigated topics. Fourthly, although other factors, such as energy trade, energy production, etc., are also important, these topics are rarely found in economics journals; instead, they appear either in specialist production journals or in the introductory sections of energy economy papers. It should be noted that the focus of this paper is on topics 1–3 and that topics 4–5 will receive less attention due to the lack of available literature. The literature reviewed includes a wide range of papers, including many Chinese journal articles that have not been previously cited. Some of these articles may be less rigorously 'scientific' than others and their results subject to wide errors and variability (this is particularly true for the literature on energy intensity and factor substitution), however, the aim of this review is, in part, to introduce a wider audience to the existence of the literature on China's energy economy so as to allow others to find and identify the strength of this growing field of research.[1] Understandably, this is difficult for English-only readers to access, but we believe this article, for the first time, helps to span the two sources, providing a more balanced, complete and informed source for all readers.

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 the five topics listed above. We first observe, summarize and analyze their focus and results to ascertain whether there are any differences across the studies and 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., and 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. A review of studies on China's energy economy

3.1. Energy consumption and economic growth

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

[1] Ideally, it might be better to report only **scientific** articles, however, it is not clear how such a metric of **scientific** can or should be constructed. Furthermore, the aim of this review paper is to embrace all the relevant literatures which typically have not been drawn together systematically in any other work.

Table 2
The papers that reviewed China's economic growth and energy consumption.

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

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 La 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 latter 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 2 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. The authors are critical of the papers they reviewed (Table 2, row 1) that assumed a linear relationship between energy consumption and economic growth without conducting any statistical tests of the linearity assumption. They estimate a nonlinear relationship between economic growth and energy consumption by employing a smooth transfer regression analysis (STR).

Liu et al. (2006) state that the Chinese literature reviewed in their paper (row 2) follows the approaches of the literature published in English. They then apply their methodologies to study China's energy economy where they ultimately come to the same conclusions. They estimate an extended Cobb–Douglas (C–D) 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 on 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 the 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 12 major industries of China.

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

3.1.2. What can be learned from this survey?

Here we present Table 3.1, Table 3.2 and Table 3.3 that show the papers to be reviewed and approaches, results, etc. Table 3.1 lists the studies that focus on the relationship between national aggregate energy consumption and aggregate economic growth; Table 3.2 presents the studies that

Table 3.1
Existing studies on the relationship between national aggregate energy consumption and aggregate economic growth in China.

Author(s)	Period	Approaches	ECM coefficient (*t*-statistics)	Granger causality
Zhao and Fan (2007)	1953–1976	STR	–	Energy → GDP
Chan and Lee (1996)	1953–1993	JJ, ECM	−0.76 (12.3)	Energy → GDP
Lin (2001)	1953–1994	JJ, ECM	−0.70 (7.7)	LRC, 0.88[a] (38)
Ma et al. (2004)	1954–2002	E–G, ECM	−0.05 (2.3)	Bi-directal
Wang et al. (2006)	1953–2002	TVP, Granger	–	Not fixed but vary
Zhang and Li (2004)	1961–2001	Granger	–	GDP → Energy
Yuan et al. (2008)	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. (2004b)	1978–2000	E–G, ECM	–	Bi-directal
Fan and Zhang (2005)	1978–2002	Granger	–	GDP → Energy
Wu et al. (2005)	1979–2002	E–G	–	GDP → Energy
Wang and Yao (2007)	1978–2003	ECM	Don't 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 et al. (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 et al. (2006)	1985–2003	C–D production	–	LRC, 0.28[a]
Liu et al. (2006)	1989–2003	C–D production	–	LRC, 0.14[a]
Liu et al. (2007)	1988–2005	GFEVD, GIR	–	GDP → Energy
Ma and Zhang (2005)	1990–2001	Grey linkage	–	LRC, 0.67[c]
Ma et al. (2006)	1995–2003	Grey linkage	–	LRC, 0.5–0.8[c]
Yang et al. (2004)	–	LEGM	–	–
Shao and Jia (2006)	–	Descriptive	–	–
Wan et al. (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.

focus on the relationship between disaggregate energy consumption and disaggregate or aggregate economic growth and Table 3.3 presents the papers that focus on national industrial aggregate energy consumption and aggregate economic growth. Table 3.1 is also sorted by time period which will affect the methods used and potential changing foci of the papers as issues develop.

3.1.2.1. The focus of existing studies. From Tables 3.1, 3.2 and 3.3, we can observe that the studies focus on six themes. However, most papers concentrate only on national aggregate energy consumption and aggregate economic growth (Table 3.1). Some put their emphasis on national aggregate energy consumption and national disaggregate economic growth (Table 3.2), a few focus on the provincial economy (Table 3.2, bottom) and the disaggregate economy (Table 3.3).

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 functions; 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.

Table 3.1 shows three types of results. Most studies presented 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

Table 3.2
Existing studies on the relationship between disaggregate or aggregate economic growth and disaggregate energy consumption.

Author(s)	Period	Approaches	ECM (*t*-statistic)	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)	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)	1963–2005	JJ, ECM	Bi-direct	Bi-directal
5. National economic growth and national electricity consumption				
Huang (1993a)	1950–1980	C–D function	–	LRC, 2.72[b] (12.0)
	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 (2004)	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 et al. (2005)	1952–2002	E–G, ECM	−0.65 (−2.6)	Bi-directal
Yuan et al. (2008)	1963–2005	JJ, ECM	Elect → GDP	Bi-directal
Chen et al. (2007a,b)	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 La Croix (1993)	1952–1989	Panel data	–	LRC, 0.94[b] (7.8)
7. 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).

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 et al. (2005), Wang and Yao (2007), Wang and Yang (2007), Liu (2006) and Liu et al. (2007). The third group concludes that economic growth and energy consumption Granger cause each other, i.e., that there is a bi-directional causality. The papers here include Ma et al. (2004), Yuan et al. (2008) and Han et al. (2004a,b).

It is clear that different findings can be found across the studies. On occasion, the causality results conflict across studies even for the same time period, for example, Ma et al. (2004) find that the relationship is bi-directional for the period 1954–2002 while Wang et al. (2006) find that the relationship varies in the period 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 C–D production functions 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

Table 3.3
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 and 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 and 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)
Non-metal 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 and 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 and 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 and 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)
Non-metal 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 and electric equipment	0.85 (−2.2)	−1.13 (−2.9)	−0.91 (−2.4)

Note: Panel cointegration: $y_{it} = \alpha_1 + \beta_{1i}x_{it} + \beta_{2i}z_{it} + \upsilon_{it}$, 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_1 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. Source: reported by Wang and Yang (2006).

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

unity; some are very small, for example, the elasticity of energy input is only 0.06 as estimated by Lei et al. (2007).

Turning to national disaggregate energy consumption and aggregate economic growth (Table 3.2), 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, we 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) find 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 in the period 1953–2004. 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 et al., 2005; Yuan et al., 2008; Chen et al., 2007a,b; Yuan et al., 2007). However, Shiu and Lam (2004) conclude that national electricity Granger causes aggregate economic growth. Huang (1993a) 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 (2003a,b) 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 long-run cointegration and short-run dynamic adjustment for 12 industries (Table 3.3). It is clear that some industries play a crucial role in reducing energy consumption by improving their energy efficiency, e.g., ferrous metals processing, petroleum processing and coking, electricity steam and water, nonferrous metals processing, chemical and non-metal mineral products. Their efficiency elasticities 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 of 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, non-metal 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 of column 2).

3.1.2.3. Why do the results differ?. The reasons why the reported relationships in both the long- and the short-run differ across studies are unclear; possibilities include variations in methods used, time periods studied and, importantly, data sources.

3.1.2.3.1. Do the methods used matter?. Various methods have been used to model the relationship between energy consumption and economic growth in the long- and the short-run (refer to Tables 3.1, 3.2 and 3.3 above). Typically, the methods can be categorized into two groups. Group One are traditional time series methods including ADF tests, Engle–Granger cointegration, vector error correction models (VECM) and Granger causality. As can be seen from Tables 3.1, 3.2 and 3.3, these methods are used extensively.

Group Two includes modified time series methods, production function analysis and 'other approaches', for example, the 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 et al., 2007); smooth transfer regression assuming a nonlinear relationship (Zhao and Fan, 2007); time varying parameter approaches based on state space models (Wang et al., 2006),[2] and C–D production functions (Liu et al., 2006; Lei et al., 2007; Dong and Du, 2007).

One might expect that the type of estimation method should not affect 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 opposite results (Table 3.1). Though the reasons are not obvious, as one of the reviewers pointed out, they might employ invalid or inappropriate econometric approaches or ignore the assumptions of those econometric methods.[3]

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 might be expected given Fig. 3, 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 rise from 2002, but GDP grows faster than prior trends until 2006. For the purpose of this review, therefore, we cannot easily conclude whether the variation in results comes from the different periods, as most studies include different stages of China's development.

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

[3] We thank one of the reviewers for pointing out this issue.

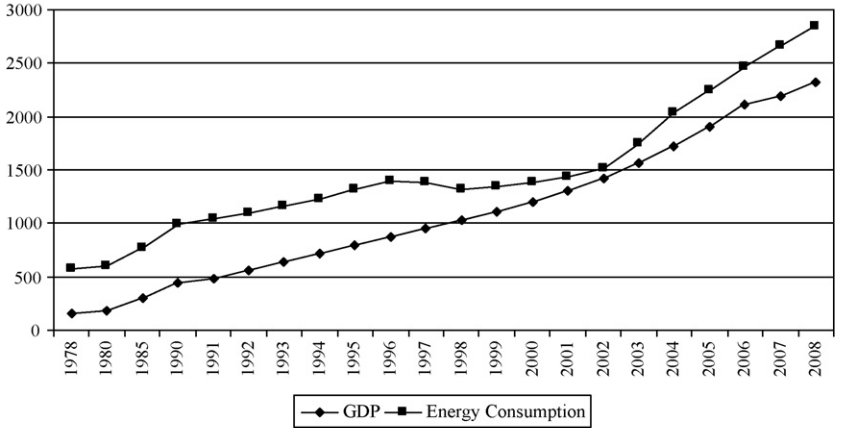

Fig. 3. China's GDP and aggregate energy consumption, 1978–2008. Note: GDP is measured in 10 billion Chinese yuan based on the 2006 price. Aggregate energy consumption is measured in million ton standard coal.*Data source*: National Bureau of Statistics of China (1979–2009).

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 do not, and 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 3.1).

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) while others only include one energy input variable (Chan and Lee, 1996; Tang and La Croix, 1993; Zou and Chau, 2006; Yuan et al., 2007; Huang, 1993b). 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 all 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 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 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 probably 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 important. Unfortunately, the literature pays little attention to this matter. Table 3.1 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, a number of energy related departments and agencies have studied energy efficiency. For example, the Office of Energy Efficiency and Renewable Energy of the United States Department of Energy (EERE, 2010) 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 assesses 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 et al. (1999) state that energy consumption per unit of GDP fell by 55% from 1978 to 1995 but ask why the energy–output ratio has fallen in China. Qi et al. (2007b) question the measure of energy intensity used in China. Zhang (2003) argues that China's industrial energy intensity fell in the 1990s. Fisher-Vanden et al. (2004) enquired as to what was driving China's decline in energy intensity and Liao et al. (2007) wish to ascertain what induces China's energy intensity to fluctuate. Moreover, as R&D in the energy sector expands, many projects in social sciences and energy efficiency have been introduced to investigate the performance of China's energy sector. The National Nature Science Foundation of China has 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. Similarly, *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 et al., 2007). Although there are various definitions of energy intensity, all should measure the same relationship between energy consumption and economic growth. Here, we use the definition of *energy intensity* defined as *the ratio of energy consumption to GDP or value-added*, $I = E/Q$.

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, index decomposition analysis has been extensively used for policymaking as its simplicity and flexibility mean it is easy to adopt (Ang, 2004). The typical index decomposition of energy intensity is defined as follows:

$$I = E/Q = \sum E_i/Q = \sum (Q_i/Q) \times (E_i/Q_i) = \sum S_i \times I_i \tag{1}$$

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:

$$\Delta I = I^t - I^0 \tag{2}$$

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

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

where superscripts t and 0 represent report year and base year, respectively; $\Delta I_{\text{int}} = \sum S_i^t (I_i^t - I_i^0)$ and $\Delta I_{\text{str}} = \sum I_i^0 (S_i^t - S_i^0)$ 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:

$$D_{tot} = I^t / I^0 \tag{4}$$

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

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

where $I_{\text{int}} = \sum S_i^t I_i^t / \sum S_i^t I_i^0$ and $I_{\text{str}} = \sum I_i^0 S_i^t / \sum I_i^0 S_i^0$ 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 acts as revision of the basic principles of index numbers. Equations (2) and (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 arithmetic mean divisia indices (MAMD), arithmetic mean divisia indices (AMDI), and logarithmic mean divisia indices (LMDI). For detailed decomposition formulae and a discussion, see Ang (2004, 2005) and Liu and Ang (2003), and for more theoretical discussions on index numbers, see Diewert (2007).[4]

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 et al. (2007) use panel data regression models.

[4] Thanks to one of the reviewers for calling this to our attention. As this review is focused primarily on a review of the literature on the energy sector rather than a full discussion of index number theory, we provide some references to the theoretical literature on index numbers for readers who require further explanation.

Table 4
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 et al. (2007a)	Light and heavy industry	1995–2000	Laspreyres	−111	11	Modified
Qi et al. (2007a)	Light and heavy industry	2000–2005	Laspreyres	−108	8	–
Han et al. (2004a)	Three industries	1981–1990	General index	−25	−75	–
Han et al. (2004a)	Three industries	1981–2000	General index	−87	−13	–
Han et al. (2004a)	Three industries	1991–2000	General index	−125	25	–
Ding et al. (2007)	Three industries	1994–2005	General index	−102	2	Substitute
Kambara (1992)	Three industries, five subsectors	1980–1990	Descriptive	≈−30	≈−70	–
Sun (1998)	Three industries, six subsectors	1980–1994	*Laspeyres*	−124	24	Modified
Qi and Chen (2006)	Three industries, six subsectors	1996–2001	Laspreyres	−114	14	Modified
Gao and Wang (2007)	Three industries, six subsectors	1996–2001	LMDI	−113	13	Estimated
Qi and Chen (2006)	Three industries, six subsectors	2002–2003	Laspreyres	42	58	Modified
Gao and Wang (2007)	Three industries, six subsectors	2002–2005	LMDI	70	30	–
Ma and Stern (2008)	Three industries, 34 subsectors	1997–2002	LMDI	−105	5	–
Ma and Stern (2008)	Three industries, 34 subsectors	1994–2003	LMDI	−110	−10	–
Ma and Stern (2008)	Three industries, 34 subsectors	2002–2003	LMDI	46	54	–
Peng and Zhang (2007)	Five industrial subsectors	1995–2003	Laspreyres	−125	25	Estimated
Zhou and Li (2006)	Six industrial subsectors	1981–1990	Divisia indices	−40	−60	–
Zhou and Li (2006)	Six industrial subsectors	1991–2001	Divisia indices	−114	14	–
Zhang and Ding (2007)	Six industrial subsectors	1994–2001	General index	−112	12	Modified
Shi (2007c)	Six industrial subsectors	1995–2000	Laspreyres	−111	11	–
Zhang and Ding (2007)	Six industrial subsectors	2001–2003	General index	20	80	Modified
Zhou and Li (2006)	Six industrial subsectors	2002–2003	Divisia indices	55	45	–
Shi (2007c)	Six industrial subsectors	2000–2005	Laspreyres	69	31	–
Hu (2007)	Thirteen industrial subsectors	1987–1997	IOSDA	−99	−1	–
Lin and Polenske (1995)	Eighteen industrial subsectors	1981–1987	IOSDA	≈−100	≈0	Lin (1996)
Garbaccio et al. (1999)	Twenty-nine industrial subsectors	1987–1992	IOSDA	<−100	>0	–
Zhang (2003)	Twenty-nine industrial subsectors	1991–1999	ALI	−82	−18	–

Table 4 (*Continued*)

Author(s)	Economy	Period	Approach	Contribution to change in energy intensity (%)		Note
				Industrial intensity	Industrial structure	
Zha et al. (2009)	Thirty-six industrial subsectors	1993–2003	AMDI	−90	−10	–
Liao et al. (2007)	Thirty-six 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)	Eleven to forty-nine industrial subsectors	1985–1990	*Laspeyres*	−90	−10	GOV
Yu (2007)	Three industries, five subsectors	1990–1995	General index	−120	20	Guangdong
Yu (2007)	Three industries, five 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.

3.2.3. What can be learned from existing studies?

Here we first present Table 4, which lists the studies to be reviewed. Table 4 is arranged by economic or industrial disaggregation and then sorted by time period. We start our analysis by identifying and 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 economy into various industries or sectors and calculate the energy intensity and output shares by industry or sector and by year. From Table 4, column 1, we can see that most studies disaggregate the economy into three or six 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, 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 4 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: individual industrial or sectoral energy intensity and its output shares. Therefore, in Table 4, we 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 4:

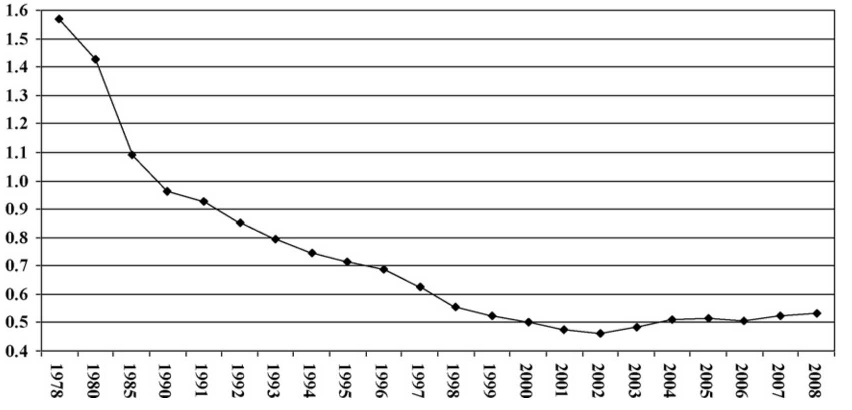

Fig. 4. Energy intensity (ton/1000 RMB) measured by the ratio of aggregate energy consumption (million ton standard coal) to GDP (billion RMB in 1978 price).*Data source*: National Bureau of Statistics of China, 1994–2009.

a. Most of the studies identify decreasing energy intensity during their study periods, for example, those whose study periods end in 2000, i.e., Qi et al. (2007a), Han et al. (2004a), Qi and Chen (2006), Gao and Wang (2007), Zhang and Ding (2007), Shi (2007a), 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, 2007c).
b. Some studies show that declining industrial energy intensity plays a larger part in reducing aggregate energy intensity than structural change, while some studies show that structural changes play a larger role. What is the explanation? Looking at these two groups of studies shows they belong to different periods. In the 1990s or later industrial energy intensity plays a larger part (Qi et al., 2007a; Han et al., 2004a (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, 2007a; Zhang, 2003). In the 1980s or earlier, structural change plays a larger part (e.g., Smil, 1988; Han et al., 2004a; 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 et al. (2007a) 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, 2007c). These results seem consistent with the trend of energy intensity (Fig. 4).
d. All results in these studies are 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 (Fig. 3), we may conclude that: (i) before the 1990s, industrial structural change plays a larger part in the decrease of aggregate energy intensity, while after the 1990s it is 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, then changed little until 2008.
f. The reasons why aggregate energy intensity decreased post-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, 2007a). However, the ideal distribution of the contribution share might be 50:50 (Table 4).
g. Given the observations and comparisons above, the existing studies under review have reached a fairly consistent view on the change in and determinants of aggregate energy intensity in China, even though a range of definitions of index decomposition and methods have been 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). Therefore, it is hard to derive a more extensive economic explanation of the change in energy intensity based on the index decomposition approach because there are other factors responsible for the changes of energy intensity other than technological progress and structural change which are not separately identifiable. These other factors include economic growth, input factor substitution, and consumption behavior. This means that the change in energy intensity for an individual sector identified by the index decomposition approach may not be completely caused by technological or structural change; for example, the substitution between energy and labor may reduce energy consumption and therefore energy intensity. Increasing the price of energy and therefore reducing the demand for energy will ultimately result in a decrease in energy intensity.
b. There is little basis for choosing one definition over the other. Howarth et al. (1991) demonstrate 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 variation across the six approaches (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.

3.2.4.2. On the variations of results post-2000. What is driving the change in energy intensity after 2002 remains unclear. Empirically, it may be better to break a long period of energy intensity change into various homogeneous stages before engaging in any index decomposition of energy. In addition, the differences in their data coverage and accuracy can also be important reasons.[5]

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 et al. (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 by the price of 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, 2009b,c), and Fan et al. (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 5 provides results for all studies on this topic ordered first by country, then by scope of study, time period, methodologies, and finally empirical results. Qian and Wang (2003) estimate the elasticity of energy-labor substitution using a C–D production function and national aggregate

[5] Thanks to one of the reviewers for pointing out this issue.

Table 5
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 He (2006)	China	National	1985–2003	Second order CES production, EKL, T	0.685	–	–
Fan et al. (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 et al. (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.
***, ** and * denote significant at the 1%, 5% and 20% level, respectively.
[a] Orishima elasticity of substitution (MES).
[b] In 1971.

economy time series data. Their estimates are −0.863 for 1993–2000 and 0.117 for 1979–1992 and suggest that energy and labor are complementary for the period 1993–2000, but substitutes in the earlier period.

Zheng and Liu (2004a)[6] 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 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 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 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 5, second half section).

Huang and He (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,b), their estimate seems more reasonable. Unfortunately, they didn't provide the estimates of the elasticity of energy-labor substitution.

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 et al. (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 the 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 highlighted. 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, particularly in 2000;

[6] 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.

for example, the estimated elasticity of substitution of coal-electricity is −1.88 in 2000, but it is tiny in the other years for the chemical industry. The same can be shown 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 et al. (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 have been ignored by Chinese scholars of energy economics. Even the effects of substitution between energy and other factors on energy consumption are often mistaken as a type of technological progress in mainland China (Guo and Wang, 2005). Wei et al. (2007) do not refer to any effects of factor substitution in their Chinese working papers and publications.[7] Likewise, it seems that Shi (1999, 2002a,b, 2003, 2006, 2007a,b) hasn't published results on the substitution of energy and other factors in her Chinese academic work.[8]
b. When we do find some results in these areas, the estimated substitution elasticities of energy and capital vary considerably, and some are quite unrealistic; for example, the substitution elasticity of energy and capital is reported to be 2.5 in Zheng and Liu (2004b), while it is 0.69 in Huang and He (2006). Moreover, these elasticities are much larger than those estimated for South Korea (0.78), Portugal (0.89) and Germany (0.87) (see Table 5).
c. The reasons why these estimated elasticities of energy-capital substitution are so large and unstable have not been fully explained, however, there are several potential factors. Firstly, model specification appears to be important. For example, there is no interaction term for energy price and output in Fan et al. (2007). Secondly, sample periods seem short. There are only 13 observations in Fan et al. (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 (2005) and Tong and Tong (2007), there is considerable work for researchers, especially establishing energy demand functions and estimating the possibilities of inter-factor and inter-fuel substitution.
e. To fill this gap, Ma et al. (2008, 2009b,c) 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 officials. The energy consumption data come from the China Energy Statistical Yearbook by industry and by province. The database comprises time series, cross-sectional data disaggregated by industry and province.

3.4. Energy price convergence in China

3.4.1. 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

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

[8] Shi 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.

(Lau et al., 2000; Young, 2000; Poncet, 2003, 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 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 across regions and types of commodities, which can then provide some important information on how the market works in China (Zhou et al., 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 most 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 few studies that focus 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 for market integration tests

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 35 provincial (or autonomous regions and municipal) capital cities collected at 10-day intervals over a maximum of 132 months (from 1995 to 2005). We conducted both a univariate unit root test and a panel unit root test for spot prices of coal and electricity across 35 major cities nationwide during the period 1995–2005 (for details, refer to Ma et al., 2009a). We provide results for two key energy input prices, coal and electricity, whose price convergence has not yet been reported for China, as follows:

Firstly, fewer tests are in favor of price convergence for coal and electricity than for gasoline and diesel, which suggests that coal and electricity are less likely market integrated than gasoline and diesel. Secondly, more tests are in favor of price convergence during the second sub-period than during the first sub-period, indicating that the energy market integration was gradually emerging in China, which reconciles the institutional evolution and gradual price reforms of China's energy industry. Thirdly, there are apparent variations on market integration across regions and across energies. For example, the coal market is more integrated while the electricity market is the least integrated in Beijing, Tianjin and Shanghai, probably because electricity rather than coal is the major determinant of regional economic growth. Finally, 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.

3.5. The reforms to China's energy industry

The institutional reforms in China's energy industry comprise two components. The first is administrative or regulatory system reform, the second is energy pricing deregulation. Understanding energy market reform is crucial in understanding China's current energy situation; therefore, this section reviews existing studies of the reform process. 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 papers that focus on regulatory system reform in China's energy industry. Andrews-Speed et al. (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 post-1998. They 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 on the third objective.

Regulatory reform of the electricity industry is the toughest area in China as electricity is a 'staple' consumption good for both residential and industry users and demand has typically been less than supply for most periods of time in China. Therefore, regulatory reform of the electricity industry has attracted more attention and has resulted in numerous studies. The most representative and comprehensive include Xu and Chen (2006), Cherni and Kentish (2007), and Ma and He (2008).

Coal is the largest source of primary energy supply in China where supply far exceeds demand. Reform of the coal industry was undertaken in the early 1990s. Andrews-Speed et al. (2000) and Wang (2007) discussed the regulatory reforms for China's coal industry where they conclude that the only outstanding issue to be reformed is the mediation system for coal sold to the state-owned power generation sector. The articles cited above did not discuss the resolution of this as the China Taiyuan Coal Exchange (CTCT) was only established in June 2007 (CTCT, 2010).

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 sector. As energy pricing plays an important role in energy consumption, energy efficiency and the energy-environment relationship, many researchers have paid attention to changes made to the pricing system, including Wu (2003), Hang and Tu (2007), Wang (2007), and Cherni and Kentish (2007). As with regulatory reform, pricing reforms in the sector have also been well documented and extensively described. Many authors not only discuss the first round of pricing deregulation which started 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 has been provided by existing studies. Although the existing literature considers all policy reforms, they do little more than describe them.
- 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, 2006). However, most of the papers reviewed simply focus on describing the reform programs.
- The existing literature criticizes the slow progress of energy sector reforms in China, which in some instances have exceeded three decades. There may be many reasons for this tardiness, but they might include the following. The energy sector is highly regulated in many/most countries as it directly impacts on many sectors and consumers. This often leads to an incentive for slow and step-wise reform due to the complexity of the sectoral linkages. In turn, this creates potential conflicts for governments when contemplating reform as these are likely to lead to increased energy prices (Birol and Keppler, 2000). Perhaps more importantly, regulatory bodies may also lack academic input and expertise, particularly model and econometric, which would be required to evaluate the potential costs and benefits of a specific policy change on a range of economic agents.

There are few papers that study the effects of energy policy reforms on changes to energy intensity and the emergence of an energy market in China. Few studies mention any effects of energy reforms on changes in energy intensity and few studies on energy market integration incorporate energy reforms into the discussion of the emergence of an energy market. These topics deserve more attention by researchers to provide evidence and advice for future policy making; for example, studies on the impact of utility restructuring on generation efficiency, environment, and social welfare have been extensively investigated in other countries (see Ma and He, 2008).

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

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 4 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 explaining changes in aggregate energy intensity. 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 et al. (2007) estimated a translog cost function, but their functional forms are also very simple (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 sector. Rawski (2001) argues that official Chinese statistics contain major exaggerations of real output growth beginning in 1998 and that 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, their quality has declined since the mid-1990s. This 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. However, 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 areas of economic interest, for example 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. These data are also disaggregated by urban and rural areas as well as by region.

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. 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. Using national aggregate information masks these regional and provincial differences and this is particularly important when investigating China's market integration (Poncet, 2003, 2005). Cross-sectional and time series fuel market price data are rarely used; exceptions include Ma et al. (2008, 2009b,c) 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 and consists of a series of five-year plans. Each five-year plan period has a special goal (e.g., growth rate) and each may have special policy measures. Within a short time period, there 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 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 is one of the most sensitive concerns related to China's membership of the WTO and the testing of various commodity market hypotheses has attracted both Chinese and foreign research (e.g., Young, 2000; Fan and Wei, 2006; Poncet, 2003, 2005). However, the energy sector has been the exception. 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 generally not been investigated, with the exception of a few recent papers. Fan and Wei (2006) use unit root tests to investigate gasoline and diesel market integration across 35 Chinese cities and Warell (2006) incorporates the Chinese coal market into an 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 et al. (2009a) 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 well integrated as a whole, but the electricity market is typically not well integrated.

Sixthly, the reasons why energy intensity has changed should have been more carefully investigated. As reviewed previously, many studies have addressed China's energy intensity; however, all of them consider only a changing industrial structure and individual industrial energy efficiency improvement as the cause. What is clear is that the current papers do little more than explain how to measure energy intensity, normally by some form of decomposition index approach. However, aggregate energy intensity clearly 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 recent studies by Ma et al. (2008, 2009b,c), has not been addressed.

Finally, as official energy data are not transparent, studies of China's energy sector are limited to very narrow fields. It seems strange to talk about 18 Asian countries' energy consumption and economic growth without including China, but many such studies do (see Liu and Ang, 2003).

5. Three policy implications

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

- Make energy production and consumption statistics more transparent, regular and available. Unlike other countries (e.g., US, Turkey, Germany, South Korea, etc.), studies of China's energy economics are relatively underdeveloped.
- Allow the free downloading of official energy economic data and international participation in the investigation of the economics of China's energy sector. 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 et al. (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 future research

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

- Factor substitution possibilities in the energy sector need more research effort. There is only one paper that focuses 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.
- Energy market integration is also an underdeveloped area. Firstly, with rapid income growth, energy consumption has also increased, making the study of energy economics more important. Secondly, no Chinese article on China's energy economics has been found which investigates China's energy

market integration. Thirdly, even the English literature on Chinese energy economics comprises only one paper focusing on China's market integration, covering only two fuels (gasoline and diesel). In addition, the study of energy market integration is an important part of any investigation of national market integration in China, especially in relation to the WTO.

- The study of regional or provincial energy economics is worthy of more attention. Several points arise here: Firstly, interregional variations 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 considering simple national aggregate time series, cointegration 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.
- 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 as a result are less likely to reach a consensus. Therefore, conducting any long-run economic relationship needs to consider and test for changing policy environments first and then break the sample into various different periods as required. This also applies to the study of both national and regional energy markets.
- Energy market price data have never been explored when studying China's energy economics. Fan et al. (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 economy studies have tried to predict China's future energy demand and consumption, but none of them have used energy market price information to establish the energy demand function and to estimate elasticities of demand for energy (as well as factor substitution).[9] As a consequence, it may not be a surprise that there are significant differences among the published predictions of China's future energy demand (Crompton and Wu, 2005). Based on the papers reviewed here, it seems clear that China's energy price data availability has impacted researchers' ability to conduct a comprehensive study of China's energy economics.
- 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 an 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.

Acknowledgement

The authors are grateful for the helpful comments and suggestions from two anonymous reviewers and the editor. Financial support from Henan Education Committee, Zhengzhou, China (2009-GH-054) and The College of Business and Economics, University of Canterbury, New Zealand, are appreciated.

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

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