China’s Energy Economy:

Technical Change, Factor Demand and Interfactor/Interfuel Substitution

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Abstract

With its rapid economic growth, China’s primary energy consumption has exceeded domestic energy production since 1994, leading to a substantial expansion in energy imports, particularly of oil. China’s energy demand will increasingly have a significant impact on global energy markets. This paper uses a two-stage translog cost function approach to estimate factor demand and Interfactor/Interfuel Substitution for China aggregate economy and industrial economy. The results on interfactor substitution suggest energy and capital, energy and labour and capital and labour are substitutes in the aggregate economy. On interfuel substitution, coal and electricity are significantly substitutable, while coal and diesel are significantly complementary. Gasoline and diesel are significantly substitutable likewise, electricity and diesel. The paper also finds that China’s energy intensity is increasing during the study period (1995-2004) and the major driver is due to the increased use of energy intensive technology.

Keywords: China; Interfactor/interfuel substitution; Technology; Energy intensity decomposition
JEL classifications: D24, O33, Q41

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Introduction

With a population exceeding 1.3 billion and economic growth over the past two decades averaging around 8% per annum, China’s demand for energy has surged to fuel both its rapidly expanding industrial and commercial sectors and the rapid rise in households’ living standard (Crompton and Wu, 2005). Before 1994, China’s primary energy consumption was less than that of Russian Federation and only 30% of the consumption of the United States. However, since then China has become the second largest energy consumer in the world, with consumption at 60% of that in the United States and more than double that of the Russian Federation (Crompton and Wu, 2005; Lewis et al., 2003). At the same time, China has also become the second largest consumer of petroleum products in 2004, having surpassed Japan for the first time in 2003, with total demand of 6.5 million barrels daily (Asif and Muneer, 2006). China consumed 1.39 billion tonnes of oil equivalent primary energy and accounted for 13.6% of world total primary energy consumption in 2004 (BP, 2005). In contrast, China’s share of global energy consumption was only 7.8% in 1985 and 10.5% in 1995. This rising share of world consumption reflects the five percent per annum growth rate of primary energy consumption in China during the last two decades.

China consumed 1.39 billion tonnes of oil equivalent of primary energy and accounted for 13.6% of the world total primary energy consumption in 2004 (BP, 2005). Due to the rapid increase of energy consumption, China’s global share of energy consumption has been increasing stably during the last two decades. The annual growth rate of primary energy consumption has been approximate 5% during the last two decades. As a result, China’s global share of energy consumption was only 7.8% in 1985, but it reached 10.5% in 1995 and 13.6% in 2004 (BP, 2005).

Primary energy consumption in China has exceeded domestic energy production since 1994, leading to a substantial expansion in energy imports, particularly of oil. Consequently, China's dependency on energy imports is constantly increasing. In the early 1980s, China still ran a slight surplus for primary energy production with primary energy production 4% more than consumption in 1981. This situation began to deteriorate gradually since the mid 1990s with domestic production 3.9% below primary energy consumption in 1995 and 7.7% below by 2004. The imbalance between production and consumption of energy varies considerably across different energy sources. Generally, China's energy shortage is primarily caused by the huge oil deficit. Although China had, on average, 25% more oil production than consumption during the 1980s, its oil consumption increased so dramatically to create a large oil deficit after 1995. For example, the oil deficit was only 7.3% in 1995, but it was as high as 43.5% in 2004. This means that China now has to import nearly 50% of its total oil consumption and its moves to ensure security of supply from overseas have recently created political issues (Stokes, 2005).

The fast growth of China's energy consumption has attracted attention both domestically and overseas. As a result, many predictions of China's energy consumption have been made for the coming decades. However, there are significant differences in the predictions of energy consumption across studies. Smil (1989, Chapter 4) documented seven separate demand forecasts conducted by economists and found their estimates differed widely, ranging from a maximum demand of 1212 million tons oil equivalent (MtOE)[1] to a minimum of 701 MtOE by the year 2000. In fact, consumption in that year was 766 MtOE (Table 1). Predictions by Shi and Zhao (1999) that China's total energy consumption would increase from about 920 MtOE in 2001 to 1150 MtOE in 2005 and 1550 MtOE in 2015 also proved wrong because energy consumption had already reached 1386 MtOE by 2004.

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[1] One ton oil is equivalent to 1.98 ton coal, equivalent to 900 cubic meters natural gas, and equivalent to 4.42 tWh of electricity.

The continued growth in energy consumption and the changes in the consumption structure away from coal raise important issues for the security of China's energy supply. In fact, recent years have shown that energy shortages can have a serious effect on economic development in China (Lin, 2004; Crompton and Wu, 2005; Asif and Muneer, 2006). At the end of 2004, China had 114.5 billion tonnes of coal reserve, which is 12.6% of the world's proven recoverable reserves (BP, 2005). Most of these reserves are steaming coal suitable for electricity generation (Crompton and Wu, 2005) and can last at least 80 years based on a nil growth rate (Asif and Muneer, 2006). However, the supply of alternative fuels is less secure because oil reserves can only last 9 years even at a nil growth rate (Crompton and Wu, 2005; Asif and Muneer, 2006).

Moreover, after two decades of rapidly rising incomes and consumption of energy products, China's citizens are becoming more environmentally aware and Chinese policy makers also have begun acknowledging the need to resort to cleaner sources of energy. As a result, public policy aims to see the share of coal consumption decline gradually and the shares of oil, gas and electricity increasing substantially. This situation makes the supply situation for these cleaner sources of energy supplies more severe. For example, electricity networks of twenty-two provinces experienced a severe shortage of electricity supply in 2003, of which ten networks had to switch off some electricity consumers even during off-peak time. Consequently inadequate electricity supply has caused severe negative effects on China's economic growth (Lin, 2004).

Given the above situation, China's energy demand will increasingly have a significant impact on global energy markets. As the source of around 40% of world oil demand growth over the past four years and with year-on-year growth of 1.0 million barrels daily in 2004, China's oil demand is a key factor in world oil markets (Asif and Muneer, 2006). Furthermore, rapid expansion of highway and air traffic has created a surge in demand for other oil products, putting pressure on petroleum prices all around the world (Skeer and Wang, 2007). Meanwhile, as an important actor in regional energy markets and a major player in regional and global environmental issues, China has drawn increasing attention internationally to its energy system (Sinton and Fridley, 2002).

The ease with which energy may be substituted for by other types of inputs is of great importance in predicting economic disruptions arising from energy shortages as well as for understanding the energy implications of public policy (Christopoulos and Tsionas, 2002). In fact, one issue central to energy policy, planning and analysis is the extent to which other factors can substitute for energy in the economy (Ozatalay et al, 1979). For example, in an early contribution Hogan and Manne (1977) show that if the elasticity of substitution between energy and an aggregate of all other economic factors is in the range of 0.3-0.5, economic growth in the United States to the year 2010 is predicted to be only slightly impeded by even dramatic constraints on growth in energy supply. Conversely an elasticity of 0.1-0.2 implies a significant depressive effect on the economy if shortage of fuels and electricity occur. Therefore, it is important to study the substitution possibilities between energy and non-energy inputs if one is interested in deriving implications of increasingly scarce and higher priced energy inputs (Berndt and Wood, 1975). Specifically, if energy and capital are substitutable, ceteris paribus, then higher price energy will increase the demand for new capital goods, while if energy and capital are complementary, then ceteris paribus, higher price energy will dampen the demand for energy and the demand for new plant and equipment. In addition, having estimates of energy substitutability can assist in addressing important issues, including the feasibility of various energy demand profiles and the valuation of alternative environmental policies (Halko and Tsionas, 2001; Christopoulos and Tsionas, 2002; Frondel, 2004).

The importance of energy consumption to economic growth, investment and employment has been recognized worldwide (See Stern (1992) for a review in the

1980s and Fatai et al. (2004) for a more recent review). The energy economy has been extensively studied in many countries. For example, analysis of energy demand and substitution in the US economy was carried out following the first oil shock in the early 1970s (Hudson and Jorgenson, 1974; Berndt and Wood, 1975; Hoffman and Jorgenson, 1977; Berndt and Wood, 1979; Ozatalay et al, 1979; Field and Grebenstein, 1980) and continued in the 1990s (Debertin, et al, 1990; Moroney, 1992; Morrison, 1993). Moreover, as early as 1976, Griffin and Gregory studied intercountry energy substitution responses for Belgium, Denmark, France, West Germany, Italy, Netherlands, Norway, United Kingdom and United States. Energy demand and substitution in the Greek economy have been extensively covered by Lianos (1975), Caramanis (1979), Kintis and Panas (1989), Caloghirou et al. (1997), Christopoulos (2000) and Christopoulos and Tsionas (2002). Interfactor and interfuel substitution in the Korean economy has been considered by Cho et al. (2004). Substitution between energy and non-energy inputs in the Netherlands was studied by Magnus as early as 1979.

Relatively, the search for causality (and cointegrating relationships) between energy consumption and economic growth in China has been extensively studied (Shiu and Lam, 2004; Zou and Chau, 2006; Han et al., 2004; Wang et al., 2005). A related literature studies why the energy-output ratio has fallen through time in China (Garbaccio et al., 1999; Fisher-Vanden et al., 2004). Studies of energy efficiency across industries have argued that the falling energy-output ratio is due to an improvement in industrial energy efficiency (Price et al., 2001; Sinton and Levine, 1998; Sinton and Fridley, 2000). Hu and Wang (2006) study total factor energy efficiency of the regions in China and argue that energy efficiency in China eventually improved with economic growth. Others studies forecast China’s future energy consumption based on time series analysis of energy consumption and economic growth (Intarapravich et al., 1996; Chan and Lee, 1996; Crompton and Wu, 2005).

Yet without knowing the substitution possibilities between inputs it is impossible to predict how increasingly scarce and higher priced energy will dampen the demand for energy and the demand for new plant and equipment (Berndt and Wood, 1975). As a result, it is unclear how Chinese economic growth will be affected by increasingly costly energy. Given that the substitutability of fuels is of particular importance in China (Intarapravich et al., 1996), it is surprising that there are no studies that are focused on the relationship between energy and nonenergy inputs and on the relationship between fuels for China.

The focus of this study, therefore, is on two issues. Firstly, technological change, factor demand and interfactor and interfuel substitutability across major industries and regions of China are studied. The second contribution is a decomposition of China's changing energy intensity to ascertain its driving forces. The next section introduces the approach used in this study followed by data sources and variable construction. Section four presents our estimated results and last section concludes.

Methodologies

It is typical in the energy economics literature to employ a translog cost function to estimate energy demand elasticities. Moreover, the translog cost function is a convenient specification of duality theory that has been favoured in empirical studies and as the second order approximation, its application allows one to avoid the need to specify a particular production function (Stratopoulos et al., 2000). Nor is it necessary to assume constant or equal elasticities of substitution (Woodland, 1975). By modeling how a change in an individual fuel price affects fuel consumption through the feedback effect between the interfuel and interfactor substitution, we assume that the production function is weakly separable in the major components of energy, capital and labor. This assumption allows us to construct an aggregate energy-price index from fuel prices. We can then assume that energy, capital and labor are homothetic in their components so that we can specify a homothetic fuel cost share equation. Under these assumptions, empirically, a second-order approximation cost function in time, the logged input price and output is be used for non-homothetic translog total factor cost function:

$$(1)\quad \ln C = \beta_0 + \sum_{i=1}^{N} \beta_i \ln P_{it} + \frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} \beta_{ij} \ln P_{it} \ln P_{jt} + \beta_t t + \frac{1}{2}\beta_{tt} t^2 + \beta_y \ln Y_t + \frac{1}{2}\beta_{yy}(\ln Y_t)^2 + \sum_{i=1}^{N} \beta_{iy} \ln P_{it} \ln Y_t + \sum_{i=1}^{N} \beta_{it} t \ln P_{it} + \beta_{yt} t \ln Y_t$$

Where ln indicates the natural logarithm; C is the equilibrium total cost; P_{jt} (P_{it}) denotes the price of input *j* (*i*) at time *T;* Y_t is the level of output in period *T* and *t* denotes a time trend reflecting biased technical change. With the proper set of restrictions on its parameters, equation (1) can therefore be used to approximate any of the unknown cost and production functions. The symmetry restrictions are

$$(2)\quad \beta_{ij} = \beta_{ji} \quad \mathit{for\,all}\ i \neq j$$

Which implies equality of the cross-derivatives. Linear homogeneity in prices (when all factor prices double, the total cost has to double) requires the following regularity conditions:

$$(3)\quad \sum_{i=1}^{N} \beta_i = 1, \sum_{j=1}^{N} \beta_{ij} = 0, \sum_{i=1}^{N} \beta_{iy} = 0, \sum_{i=1}^{N} \beta_{it} = 0,\ i = 1,\cdots,N$$

By Shephard's lemma, a firm's system of cost minimizing demand functions (the conditional factor demands) can be obtained by differentiating the total cost function with respect to input prices to obtain the following system of factor share equations:

$$(4)\quad S_{factor} = \beta_i + \sum_{j=1}^{N} \beta_{ij} \ln P_{jt} + \beta_{iy} \ln Y_t + \beta_{it} t$$

Following a two-stage approach suggested by Pindyck (1979), we first estimate the homothetic translog fuel cost share functions assuming constant returns to scale. The resulting parameter estimates yield the partial own- and cross-price elasticities of the fuel sources and the computed fitted fuel cost ($\hat{P}_E$) from the estimated parameters serves as an instrumental variable for the aggregate price of energy (P_E), from which we can estimate the non-homothetic translog factor cost function using the computed $\ln \hat{P}_E$ from the following homothetic translog aggregate energy price index function:

$$(5)\ \ln P_E = \gamma_0 + \sum_{i=1}^{N} \gamma_i \ln P_i + \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} \gamma_{ij} \ln P_i \ln P_j + \sum_{i=1}^{N} \gamma_i t \ln P_i$$

By differentiating equation (5) with respect to individual fuel price, we have the following fuel share equations:

$$(6)\ S_{fuel} = \gamma_i + \sum_{j=1}^{N} \gamma_j \ln P_j + \gamma_i t$$

The Allen partial elasticities of substitution (σ_{ij}) and own-price elasticities (η_{ii}) and cross-price elasticities (η_{ij}) of factor demand for the production process are given by equations (7) and (8) (Allen, 1938; Uzawa, 1962):

$$(7)\ \sigma_{ij} = 1 + \beta_{ij} / S_i S_j \quad \forall\, i \neq j \quad and \quad \sigma_{ii} = (\beta_{ii} + S_i^2 - S_i) / S_i^2$$

$$(8)\ \eta_{ii} = \sigma_{ii} S_i \quad and \quad \eta_{ij} = \sigma_{ij} S_j \quad \forall\, i \neq j \quad for\ i, j = E, K, L$$

where S_i is the share of *i*th factor. A positive σ_{ij} between factors *i* and *j* indicates that they are substitutes, while a negative σ_{ij} implies that the factors *i* and *j* are complementary. Total own- and cross-price elasticities of fuel demand can be estimated as follow (Pindyck, 1979; Cho et al., 2004):

$$(9)\ \eta_{ii}^{*} = \eta_{ii} + \eta_{EE} S_i \quad and \quad \eta_{ij}^{*} = \eta_{ij} + \eta_{EE} S_j$$

Where *i* and *j* are individual fuel source and η_{EE} is the own-price elasticity of aggregate energy use. Likewise, the Allen partial elasticities of substitution (σ_{ij}) between fuels and conditional own-price elasticities (η_{ii}) and conditional cross-price elasticities (η_{ij}) of fuel demand can be estimated by equations (7) and (8) using the estimated parameters from equation (6). To attribute changes in energy intensity (e) to various driving forces, such as factor substitution and technological change, one can observe that $e = E/Q = (P_Q / P_E) S_E$, where P_Q is the output price, P_E is aggregate energy price, and S_E is aggregate energy factor share in total factor cost function. Following Welsch and Ochsen (2005), we decompose the energy intensity as follow based on the estimated parameters of the aggregate energy share equation:

$$
\begin{aligned}
(10)\quad e &= E/Q = (P_Q/P_E)S_E \\
&= \frac{P_Q}{P_E}(\hat{\beta}_E + \hat{\beta}_{EE}\ln P_E + \hat{\beta}_{EK}\ln P_K + \hat{\beta}_{EL}\ln P_L + \hat{\beta}_{iy}\ln Y + \hat{\beta}_{Et}t) \\
&= [\frac{P_Q}{P_E}\hat{\beta}_E] + [\frac{P_Q}{P_E}\hat{\beta}_{EE}\ln P_E] + [\frac{P_Q}{P_E}\hat{\beta}_{EK}\ln P_K] + [\frac{P_Q}{P_E}\hat{\beta}_{EL}\ln P_L] + [\frac{P_Q}{P_E}\hat{\beta}_{iy}\ln Y] + [\frac{P_Q}{P_E}\hat{\beta}_{Et}t]
\end{aligned}
$$

where $\hat{\beta}$'s are the estimates of β's. Energy intensity is decomposed into the six terms in square brackets on the right hand side of equation (10), denoted by $\hat{e}_0, \hat{e}_1, \hat{e}_2, \hat{e}_3, \hat{e}_4, \hat{e}_5$, respectively. The terms, $\hat{e}_1, \hat{e}_2, \hat{e}_3$, which include input price and associated substitution parameters, represent the contribution of factor substitution to the variation in energy intensity. The term $\hat{e}_4$ measures the effect of the change in output on energy intensity, while term $\hat{e}_5$ measures the contribution of technological change (Welsch and Ochsen, 2005). The straightforward way of allocating changes in energy intensity to various driving forces can be expressed by:

$$(11)\quad \frac{\Delta\hat{e}}{\hat{e}} = \sum_{i=0}^{4}\frac{\Delta\hat{e}_i}{\hat{e}_i}\frac{\hat{e}_i}{\hat{e}}$$

Where $\Delta\hat{e}/\hat{e}$ and $\Delta\hat{e}_i/\hat{e}_i$ denote relative changes over time, $\hat{e}$ and $\hat{e}_i$ indicate base year level of energy intensity. The terms on the right hand side can be of uneven sign, where respective signs indicate whether one of drivers has reduced (negative sign) or enhanced (positive sign) energy intensity, respectively.

Data and Variables

To conduct this study, we use three factor inputs (E-aggregate energy use, K-capital stock and L-labor use) to construct factor share series and three factor price indices

(P_E-aggregate energy price index, P_K-capital stock price index and P_L-labor wage rate index), gross domestic product (GDP as total output) across sectors and its deflator for the total factor cost function. We also need individual fuel consumption and price data to construct fuel cost share series for the fuel cost share equation. The three main sources of information for this study are the China Statistical Yearbook, China Energy Yearbook and State Development Planning Commission of China. The China Statistical Yearbook (CSY) provides detailed data for employment (including total employment and wages), capital investment (including replacement and new investment), and gross domestic product (GDP) across major sectors, the consumer price index, and a fixed assets price index. Unfortunately, the CSY does not provide a capital stock index for each sector. Therefore, to construct a capital stock series, we employ the following equation:

(12) $K_t = K_{t-1}(1-\delta) + I_t$

Where K_t is current capital stock, K_{t-1} is previous year capital stock, δ is capital depreciation rate, and I_t is current year capital investment (which actually formed capital). The total capital stock in 1994 comes from Table 4 of Li (2003). We can then decompose this number into agriculture, industry, construction, transportation and commerce based on capital replacement investment in 1994. The total capital depreciation is taken as capital at factor cost, which is consistent with current cost accounting system in China and GDP as an output indicator. Since the GDP deflator is not available from the CSY, we have to employ a weighted price index of the consumer price index and the fixed assets price index to deflate GDP as GDP mainly consists of labor and capital costs.

The China Energy Yearbook (CEY) provides detailed data on energy consumption by fuels and sectors and by province and year. The energy consumption data used in this study cover mainly raw coal, electricity, gasoline and diesel. For analysis of aggregate energy, fuels are grouped into four input variables, but at the industry level fuels are classified into three types (gasoline and diesel are combined into one variable-oil and therefore the oil price series is weighted by both price series of gasoline and diesel) because gasoline and diesel consumption in the industrial sector accounts for a very small share of energy cost. In fact, Cho et al. (2004) only employ three fuels – coal, electricity and oil.

Individual fuel price data are obtained from the State Development Planning Commission (SDPC). The SDPC collects fuel price data from 150 city price bureaus nationwide and covers coal, electricity, natural gas, crude oil, gasoline, diesel, kerosene, fuel oil and rural diesel and electricity. The fuel price data were initially reported and recorded each 10 days. For this study, we aggregate these 10 day data into an annual fuel price series. The full sample period is 1995-2004. Finally, we have transformed these fuel price data into a price index based on 1995.

Results

Employing the iterative Zellner's seemingly unrelated regression technique, we estimate the system of translog fuel cost equations first (equation (6)). The aggregate energy price index (P_E) is generated using the parameters from this stage. The parameter γ_0 in equation (5) is determined so that $P_E = 1$ in 1995 (Pindyck, 1979) and a relative energy price index is calculated for each region. Then equations (1) and (4) are estimated simultaneously using the same regression technique. Both symmetry and homogeneity restrictions in price are imposed and therefore one of the share equations is dropped.

Because of the panel datasets used in this study (30 provinces and 10 years), we have to group them into regions according to the characteristics of energy production and consumption as well as location and level of aggregate economy so as to remove some dummy variables.[2] Empirically we define the parameters in equations (1) and (5) to be

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[2] Region 1 includes Hebei, Shanxi, Anhui, Shandong and Henan; region 2 includes Beijing, Tianjin, and Shanghai; region 3 includes Liaoning, Jilin and Heilongjiang; region 4 includes Jiangsu, Zhejiang, Jiangxi and Hubei; region 5 includes Fujian, Hunan, Guangdong, Guangxi and Hainan; region 6 includes Chongqing, Sichuan, Shaanxi, Gansu,

a function of regional dummy variables (except for the interaction of prices in equation (1)). To demonstrate whether these definitions are suitable, we conduct a series of hypothetic tests on these regional dummy variables (the results are listed in Table A8) and the results show that all tests are statistically significant (except for $\sum D_{\mathrm{k}} \mathrm{p}_{\mathrm{j}} \mathrm{t}$ in fuel share equations), which suggests that almost all production behaviors are different across regions. The hypothesis tests also illustrate that the translog cost function should be chosen to analyze China's energy demand.

Interfactor Substitution

Table 1 reports the parameters estimates of the translog factor cost function for the aggregate economy. This stage includes one total factor cost equation and two factor share equations (aggregate energy and capital shares - the labor share equation is dropped from the system due to the adding-up restriction). The conventional R^2 figures are 0.99 for the total factor cost equation, 0.97 for the aggregate energy share equation and 0.96 for the capital share equation. The major parameters have the correct sign and more than 50% of parameters are statistically significant. The estimated total factor cost function is well behaved as the input demand function is strictly positive and concave in the input price (Berndt and Wood, 1975).

Based on the estimated parameters of Table 1 and equations (7) and (8), the implied elasticities of substitution (σ_{ij}) and price elasticities (η_{ij}) of factor demand for the interfactor substitution for the aggregate economy are calculated and the results are shown in Table 2. Several important conclusions can be derived from Table 2.

First, energy and capital are responsive to a change in their own price, the estimated own-price elasticities η_{EE} = -0.47 and η_{KK} = -0.42. Second, energy and capital are substitutable and the estimated σ_{EK} is 0.80 with cross-price elasticities of η_{EK} = 0.11

Guizhou and Yunnan; region 7 includes Inner Mongolia, Tibet (deleted due to data unavailable), Qinghai, Ningxia and Xinjiang.

and η_{KE} =0.22 (insignificant). Third, energy and labour are significantly slightly substitutable, and the estimated σ_{EL} is 0.61 with cross-price elasticities of η_{EL} = 0.36 and η_{LE} =0.17 (significant). Fourthly, capital and labour are slightly substitutable and the estimated σ_{KL} =0.34 (statistically insignificant), with cross-price elasticities of η_{KL} = 0.20 and η_{LK} =0.05 (insignificant). Fifthly, no complementary is found among energy, capital and labour in this study at the aggregate economy level in China. As in Cho et al. (2004), all the cross-price elasticities are less than one, suggesting that there is also limited scope for substitutability of capital and labor for energy in China, and energy is Allen substitutable for the other two factors (capital and labor).

Interfuel Substitution

Table 3 reports the parameters estimates of the fuel share equations for the aggregate economy. This stage includes only three share equations (coal, gasoline and electricity) and one share equation (diesel) is dropped from the system due to the adding-up restriction. The conventional R^2 figures are 0.89 for the coal share equation, 0.91 for the gasoline share equation, and 0.98 for the electricity share equation. The major parameters also have the correct sign and are statistically significant. The estimated share equations are also checked and found to be well behaved as all the input demand functions are strictly positive and concave in input price.

Based on the estimated parameters of Table 3 and equations (7) and (8), the implied elasticities of substitution (σ_{ij}) and price elasticities (η_{ij}) of fuel demand for the aggregate economy are calculated and the results are presented in Table 4. Several important conclusions emerge from Table 4:

(i) coal and electricity are significantly substantially substitutable -- the estimated σ_{CE} =1.49;

(ii) in contrast, coal and diesel are significantly quite complementary – the estimated σ_{CD} = -1.79;

(iii) gasoline and diesel are slightly significantly substitutable – the estimated σ_{GE} =0.60;

(iv) likewise, electricity and diesel are slightly significantly substitutable – the estimated σ_{ED} =0.68.

The computed values of the fuel-price elasticities are displayed in Table 4. It can be seen that all the own-price elasticities of fuel demand are negative. It is also obvious that coal and electricity display the highest own-price elasticities (0.535 and 0.405, respectively) and are statistically significant. However, gasoline and diesel show much smaller own-price elasticites (0.214 and 0.108, respectively) and are also statistically insignificant.

Total fuel-price elasticities that reflect both the effect of a price change given the constant aggregate energy consumption and the feedback effect are presented in Table 5, which provides several notable conclusions:

(i) The estimated results suggest that all fuel sources are not only substitutable, but also complementary. For example, coal-gasoline, gasoline-diesel and coal-diesel are all complementary, but electricity-diesel and gasoline-electricity are all substitutable;

(ii) The fuel demands of coal and electricity are more sensitive to their own price change than of gasoline and diesel. In other words, the former are elastic while the later are inelastic;

(iii) Electricity demand is more sensitive to coal-price change than to gasoline- and diesel-price change, η^{*}_{EC} =0.597 and η^{*}_{EG} =0.072 and η^{*}_{ED} =0.123. This finding implies that in the long run, a coal-price change has greater effect on electricity demand rather than a gasoline-price change;

(iv) Diesel demand is more sensitive to coal-price change than to gasoline-price change, η^{*}_{DC} = -0.314 and η^{*}_{DG} = - 0.067;

The Roles of Substitution, Technologies and Production

Using equations (10) and (11), we allocate the change in energy intensity into budget, substitution, technology and output effects. The results are displayed in Table 6. From Table 6, it can be seen that the estimated energy intensity of China in the aggregate economy increased by about 7.27% during the study period (1995-2004).[3] The budget-effect is about – 19.3%, implying that it reduces energy intensity by approximately 20%. The total substitution effect on energy intensity is negligible - the price of labor suggests it falls by about 5.59%, which is almost offset by the effect of the energy price (6.19%). The capital price effect is close to zero. The most important effect, however, comes from technological change, which suggests that energy intensive technology has been employed in China during the study period. Consequently these findings suggest that overall energy intensity has increased by 7.27% from 1995 to 2004. The same types of scenario can be found across the regions except Region 3 where the energy intensity decomposition looks quite different due to a substantial budget effect (-35.89%). This leads to energy intensity in the region decreasing by 4.29%.

Though we do not have direct evidences to confirm our findings, there seem many indirect evidences that are implied in current literatures even those who conclude the rapid decline in energy intensity. Firstly, official statistics (both energy consumption and GDP) are possible to be responsible for the apparent decline in energy intensity in China. In fact, much attention has been paid to the quality of both energy consumption and GDP statistics. For example, Garbaccio et al (1999) state that problems arise when one tries to measure energy intensity because of data quality and availability.

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[3] To make the estimate more stable and reliable, we take three year averages of 1995-1997 and 2002-2004 for the base year and reporting year to calculate the growth rate of energy intensity.

Systematic underreporting of the growth of energy consumption may also be responsible for this decline in energy intensity (Fisher-Vanden et al, 2004). Figure 1 shows the trend of total energy consumption and real GDP over time. It may just be implausible for total energy consumption to be flat and even decline during 1996-2002 while real GDP is growing stably.

Secondly, Lewis et al (2003) concludes that government industrial policy was a primary factor in the energy consumption decline, supported by ongoing programs to increase energy efficiency. However, according to the results estimated by Hu and Wang (2006), China's total factor energy efficiency levels actually stagnate during the period 1995-2000 (see top section of Table 7 in Hu and Wang (2006)). This outcome looks even worse, if we consider the estimates of partial factor energy efficiency - the energy productivity ratio (see bottom section of Table 7 in Hu and Wang (2006)). Energy efficiency levels were low over 1995-2002 with the average being approximately 66% for total factor energy efficiency and less than 45% for partial factor energy efficiency. With this evidence it is therefore doubtful that energy efficiency improvement was a primary factor in the decline of energy consumption.

Thirdly, some studies conclude that technical change is one of the major drivers of decline in energy intensity. For example, Garbaccio et al. (1999) employ I-O tables, but I-O tables may have much thing to do with general statistics. Fisher-Vanden et al. (2004 and 2006) use firm level 1997-1999 panel data. During this period, energy intensity is declining, which is consistent with Figure 1. However, it may be difficult to conclude technology change is one of major divers based on three-year period of panel datasets.

Fourthly, *The Report on the Work of the Central Government of China 2006* quotes, Premier Jiaobao Wen in saying that extensive economic growth is second among four issues and shortcomings to be resolved and that the reasons are mainly due to heavy energy consumption and environmental pollution. He quotes official statistics which show that energy consumption per unit GDP *increased* annually by 4.9%, 5.5% and 0.2% in 2003, 2004 and 2005, respectively. Our results are in line with these statistics and suggest positive increases of 2.0% and 1.7% in 2003 and 2004. It should be noted that *The Report* even indicates more energy intensity increase than Figure 1, meaning either underreporting energy consumption or over-reporting GDP.

Industrial Economy

The industrial economy accounts for more than 70% of total energy consumption in China, on average, between 1995 and 2004. We employ the same methodology used above to analyze technical change, factor demand and interfactor/interfuel substitution effects on energy demand by industry. Due to gasoline and diesel consumption accounting for a very small share of energy cost, we combine gasoline and diesel into one fuel factor – oil so that there are only three fuel share equations for industry energy demand analysis in this study. The estimated parameters are presented in Table A1 for the total factor cost function and Table A2 for fuel share equations. The estimated elasticities are presented in Tables A3-A6. The results tell almost the same story for the industrial economy as for the aggregate economy. However, there are several points to note. Energy intensity increased slightly less for the industrial economy than for aggregate economy, while the patterns vary across the regions as between the industrial economy and aggregate economy. For example, energy intensity increased by 7.0% and 13.5% for the aggregate economy in regions 1 and 6 (Table 6), respectively, but only by 2.3% and 6.9% for the industrial economy in regions 1 and 6 (Table A6), respectively. For region 3, however, energy intensity decreased by 4.3% for the aggregate economy (Table 6), but declined by more than 9% for the industrial economy (Table A6). Overall, the technology effect on energy intensity is slightly weaker for the industrial economy which may imply that other sectors have employed more energy intensive technology.

The driving forces behind energy intensity also vary across regions. For example, energy intensity declined by 35.9% in region 3, but it only decreased by about 11% in regions 4 and 6 due to the budget effect at the aggregate economy level (Table 6). Energy intensity increased by 9.2% in region 3, but it only increased by 4.1% in region 4 due to the substitution of energy. Likewise, the effects of substitution of labor also vary across regions. For instance, energy intensity decreased by about 12.1% in region 2 but it only declined by less than 4% in regions 1 and 5 due to the substitution of labor (Table 6). The same can be found for the industrial economy (Table A6).

As there is no similar study on China with which to compare our estimated results Table 8 lists similar estimates for South Korea, West Germany, Greek, Portugal and Spain. However, these are for periods ten years older that those of this study. It can be seen from that Table that some estimates are quite similar, while some are quite different, not only the magnitudes, but also the signs.

Conclusions

China's demand for energy has surged to fuel both its rapidly expanding industrial and commercial sectors and the rapid rise in households' living standards. The fast growth of China's energy consumption has attracted attention both domestically and overseas. Understanding the drivers of China's energy growth and the potential for interfuel and interfactor substitution is important not only for China, but also the Rest of the World. However, given that the substitutability of fuels is of particular importance in China it is surprising that there are no previous studies that are focused on the relationship between energy and nonenergy inputs and on the relationship between fuels for China. Without knowing the substitution possibilities between alternative sources it is not possible to predict how increasingly scarce and higher priced energy will affect the Chinese economy or the Rest of the World.

This study attempts to fill some of these gaps by focussing on technological change, factor demand and interfactor and interfuel substitutability across major industries and across regions and on the decomposition of energy intensity to ascertain its driving forces. Using individual fuel price data, obtained from 150 city price bureaus covering coal, electricity, natural gas, crude oil, gasoline, diesel, kerosene, fuel oil and rural diesel and electricity and a two-stage approach, total factor cost functions and fuel share equations were estimated and the parameters used to calculate implied elasticities of substitution (σ_{ij}) and price elasticities (η_{ij}) for interfactor substitution and interfuel substitution. In addition, we decomposed energy intensity into its components.

The main findings of the study, both at the aggregate and industry level are threefold. First, energy is Allen substitutable for all capital and labor. Second, not only are all fuel sources substitutable, but our results suggest that they are also complementary. Finally, and in contrast to previous studies we find energy intensity in China to be increasing slightly rather than rapidly declining. The major driver of this result seems to be the growth of energy-intensive technologies. It should be noted that our increasing energy intensity findings, though somewhat different to other studies, are supported by statistics reported in *The Report on the Work of the Central Government of China 2006* and many indirect evidences implied in current literatures. Whether this trend in increasing energy intensity continues or declines will be significant and important for China and the rest of the World. Therefore, any decisions based upon an assumed decline in energy intensity should be treated with caution and more research would seem to be required since concerns have been expressed about the quality of official data (Garbaccio et al., 1999; Sinton and Fridley, 2000; Sinton, 2001; Fisher-Vanden et al., 2004 and 2006).

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Table 1

The Estimates of Total *Factor* Cost Function for *Aggregate* Energy Demand

Variable	Coeff.	t-stat.	Variable	Coeff.	t-stat.	Variable	Coeff.	t-stat.
P_E	0.287	3.62	P_LD4	-0.991	-5.42	P_EtD3	-0.003	-0.79
P_K	0.287	4.54	P_LD5	0.024	0.09	P_EtD4	-0.001	-0.42
P_L	0.426	4.38	P_LD6	-0.004	-0.03	P_EtD5	0.004	1.28
P_EP_E	0.070	3.62	YD1	5.359	1.23	P_EtD6	0.008	2.64
P_EP_K	-0.007	-0.42	YD2	-8.549	-2.93	P_KtD1	-0.015	-4.84
P_EP_L	-0.062	-3.70	YD3	-3.149	-2.39	P_KtD2	-0.023	-7.59
P_KP_K	0.061	2.48	YD4	0.434	0.64	P_KtD3	-0.006	-2.20
P_KP_L	-0.054	-3.31	YD5	-4.762	-5.46	P_KtD4	0.003	1.24
P_LP_L	0.116	5.20	YD6	1.853	1.44	P_KtD5	-0.002	-0.94
Y	0.628	0.96	tD1	-0.541	-1.41	P_KtD6	-0.003	-1.28
YY	0.025	0.29	tD2	0.651	2.31	P_LtD1	0.014	2.92
P_EY	-0.009	-0.87	tD3	0.190	1.18	P_LtD2	0.018	3.88
P_KY	-0.021	-2.60	tD4	0.002	0.02	P_LtD3	0.008	2.08
P_LY	0.030	2.40	tD5	0.370	3.61	P_LtD4	-0.002	-0.46
t	0.050	0.60	tD6	-0.136	-0.99	P_LtD5	-0.002	-0.44
tt	0.003	0.81	P_EYD1	0.040	1.90	P_LtD6	-0.005	-1.33
P_Et	0.010	4.59	P_EYD2	-0.035	-1.60	YYD1	-0.769	-1.25
P_Kt	-0.001	-0.38	P_EYD3	0.091	5.89	YYD2	1.201	2.99
P_Lt	-0.009	-3.54	P_EYD4	0.049	4.06	YYD3	0.411	2.35
Yt	-0.013	-1.18	P_EYD5	-0.052	-3.61	YYD4	-0.038	-0.42
P_ED1	-0.233	-1.56	P_EYD6	-0.032	-2.52	YYD5	0.667	5.52
P_ED2	0.269	1.63	P_KYD1	0.049	2.96	YYD6	-0.324	-1.51
P_ED3	-0.704	-5.88	P_KYD2	0.195	11.0	ttD1	-0.004	-0.48
P_ED4	-0.360	-3.93	P_KYD3	0.052	4.21	ttD2	0.008	1.14
P_ED5	0.358	3.43	P_KYD4	-0.022	-2.29	ttD3	0.012	1.95
P_ED6	0.189	2.09	P_KYD5	0.029	2.49	ttD4	-0.002	-0.46
P_KD1	-0.168	-1.41	P_KYD6	0.017	1.72	ttD5	0.007	1.46
P_KD2	-1.327	-10.1	P_LYD1	-0.089	-3.48	ttD6	-0.007	-1.22
P_KD3	-0.377	-3.96	P_LYD2	-0.159	-5.88	YTD1	0.079	1.48
P_KD4	0.150	2.07	P_LYD3	-0.143	-7.56	YtD2	-0.096	-2.47
P_KD5	-0.212	-2.54	P_LYD4	-0.027	-1.83	YtD3	-0.036	-1.62
P_KD6	-0.075	-1.04	P_LYD5	0.023	1.32	YtD4	0.005	0.38
P_LD1	-0.117	-0.34	P_LYD6	0.015	0.94	YtD5	-0.055	-3.81
P_LD2	1.229	5.37	P_EtD1	0.001	0.33	YtD6	0.027	1.22
P_LD3	2.350	7.15	P_EtD2	0.005	1.31			

Note: All indices are measured in term of natural logarithm, P and Y represent price and output, and D represents regions. Regional dummy variables and constant term are not shown in the table.

Table 2

Implied Elasticities of Substitution (σ_{ij}) and Price Elasticities (η_{ij}) of Factor Demand for the Interfactor Substitution for Aggregate Economy

	Elasticities	Standard Error
σ_{EE}	-1.7229**	0.2574
σ_{EK}	0.8034	0.5102
σ_{EL}	0.6130**	0.1198
σ_{KK}	-3.0342**	0.9237
σ_{KL}	0.3384	0.2168
σ_{LL}	-0.3646**	0.0645
η_{EE}	-0.4715**	0.0704
η_{EK}	0.1109	0.0643
η_{EL}	0.3606**	0.0615
η_{KE}	0.2199	0.1275
η_{KK}	-0.4189**	0.1784
η_{KL}	0.1991	0.1177
η_{LE}	0.1678**	0.0286
η_{LK}	0.0467	0.0276
η_{LL}	-0.2145**	0.0380

Note: E stands for aggregate energy, K stands for capital and L stands for labor. Elasticities are calculated with mean of each share. S_E=0.2727, S_K=0.1381 and S_L=0.5882.

Table 3

The Estimates of *Fuel* Share Equations for *Aggregate* Energy Demand

	Coal			Gasoline			Electricity			Diesel	
Variable	Coeff.	t-stat.	Variable	Coeff.	t-stat.	Variable	Coeff.	t-stat.	Variable	Coeff.	t-stat.
Cons	0.278	26.70	Cons	0.080	12.59	Cons	0.574	44.41	Cons	0.068	7.71
D1	-0.081	-3.85	D1	0.026	2.04	D1	0.022	0.84	D1	0.033	1.83
D2	0.004	0.18	D2	0.048	3.73	D2	-0.101	-3.83	D2	0.050	2.77
D3	-0.056	-2.93	D3	0.008	0.71	D3	0.004	0.18	D3	0.043	2.68
D4	-0.086	-4.87	D4	0.028	2.66	D4	-0.009	-0.42	D4	0.066	4.46
D5	0.004	0.21	D5	0.019	1.89	D5	-0.029	-1.39	D5	0.006	0.45
D6	-0.090	-4.75	D6	0.071	6.11	D6	-0.010	-0.43	D6	0.030	1.83
P1	0.051	2.74	P1	-0.035	-3.41	P1	0.046	2.65	P1	-0.062	-4.62
P2	-0.035	-3.41	P2	0.079	3.42	P2	-0.028	-1.97	P2	-0.017	-0.80
P3	0.046	2.65	P3	-0.028	-1.97	P3	0.007	0.24	P3	-0.026	-1.35
P4	-0.062	-4.62	P4	-0.017	-0.80	P4	-0.026	-1.35	P4	0.104	4.40
t	-0.011	-6.17	T	-0.001	-0.87	t	0.010	5.07	t	0.002	1.06
tD1	0.000	0.03	tD1	0.002	1.11	tD1	-0.001	-0.22	tD1	-0.001	-0.50
tD2	-0.009	-2.49	tD2	0.001	0.55	tD2	0.009	1.93	tD2	-0.001	-0.34
tD3	0.000	0.11	tD3	0.000	0.13	tD3	-0.001	-0.22	tD3	0.000	0.09
tD4	0.001	0.39	tD4	0.001	0.63	tD4	-0.002	-0.50	tD4	0.000	-0.17
tD5	-0.003	-0.99	tD5	0.001	0.93	tD5	-0.001	-0.42	tD5	0.003	1.12
tD6	0.010	3.22	tD6	-0.006	-3.37	tD6	-0.004	-0.97	tD6	0.000	0.06

Note: Coefficients for diesel share are calculated based on adding-up restriction. Prices are measured in term of logarithm.

Table 4

Implied Elasticities of Substitution (σ_{ij}) and the Price Elasticities (η_{ij}) of Fuel Demand for the Interfuel Substitution of Aggregate Economy

	Elasticities	Standard Error		Elasticities	Standard Error
σ_{CC}	-3.2666**	0.7140	η_{CC}	-0.5249**	0.1147
σ_{CG}	-0.8175	0.5338	η_{CG}	-0.1314**	0.0632
σ_{CE}	1.4948**	0.1869	η_{CE}	0.2402**	0.1088
σ_{CD}	-1.7908**	0.6043	η_{CD}	-0.2878**	0.0838
σ_{GG}	-1.8035	1.6485	η_{GC}	-0.0968	0.0858
σ_{GE}	0.5951**	0.2052	η_{GG}	-0.2137	0.1953
σ_{GD}	-0.0099	1.2603	η_{GE}	0.0705	0.1195
σ_{EE}	-0.6964**	0.0896	η_{GD}	-0.0012	0.1748
σ_{ED}	0.6826**	0.2346	η_{EC}	0.8702**	0.0300
σ_{DD}	-0.7814	1.2348	η_{EG}	0.3464**	0.0243
			η_{EE}	-0.4054**	0.0522
			η_{ED}	0.3973**	0.0326
			η_{DC}	-0.2484**	0.0971
			η_{DG}	-0.0014	0.1493
			η_{DE}	0.0947	0.1366
			η_{DD}	-0.1084	0.1713

Note: C stands for coal, G stands for gasoline, E stands for electricity and D stands for diesel. Elasticities are calculated with mean of each share (namely, S_C=0.1607, S_G=0.1185, S_E=0.5821 and S_D=0.1387).

Table 5

Total Implied Fuel-Price Elasticities (η_{ij}^{*}) of Demand for the Interfuel Substitution of Aggregate Economy

	Elasticities		Elasticities
η_{CC}^{*}	-0.6007	η_{EC}^{*}	0.5956
η_{CG}^{*}	-0.2072	η_{EG}^{*}	0.0718
η_{CE}^{*}	0.1644	η_{EE}^{*}	-0.6800
η_{CD}^{*}	-0.3635	η_{ED}^{*}	0.1228
η_{GC}^{*}	-0.1527	η_{DC}^{*}	-0.3139
η_{GG}^{*}	-0.2695	η_{DG}^{*}	-0.0668
η_{GE}^{*}	0.0146	η_{DE}^{*}	0.0293
η_{GD}^{*}	-0.0571	η_{DD}^{*}	-0.1738

Note: C stands for coal, G stands for gasoline, E stands for electricity and D stands for diesel. Elasticities are calculated with mean of each share. S_C=0.1607, S_G=0.1185, S_E=0.5821 and S_D=0.1387.

Table 6

Decomposition of the Change in Energy Intensity for the Aggregate Economy [a]

Region [b]	$\Delta\hat{e}/\hat{e}$	Budget	Substitution				GDP	Tech.
			Sum	Energy	Capital	Labor		
National	0.0727	-0.1934	0.0043	0.0619	-0.0017	-0.0559	0.0251	0.2368
Region 1	0.0702	-0.2387	0.0363	0.0701	-0.0014	-0.0324	0.0387	0.2340
Region 2	0.0550	-0.1540	-0.0581	0.0641	-0.0010	-0.1212	0.0153	0.2517
Region 3	-0.0429	-0.3589	0.0214	0.0916	-0.0019	-0.0683	0.0647	0.2299
Region 4	0.1336	-0.1123	-0.0099	0.0409	-0.0014	-0.0494	0.0071	0.2487
Region 5	0.0638	-0.2242	0.0195	0.0594	-0.0008	-0.0391	0.0341	0.2343
Region 6	0.1345	-0.1161	0.0069	0.0523	-0.0026	-0.0428	0.0095	0.2342
Region 7	0.0602	-0.1686	-0.0143	0.0656	-0.0027	-0.0771	0.0113	0.2318

[a] To make the estimate more stable and reliable, we take three year averages of 1995-1997 and 2002-2004 for the base year and reporting year to calculate the growth rate of energy intensity.

[b] Region 1 includes Hebei, Shanxi, Anhui, Shandong and Henan; region 2 includes Beijing, Tianjin, and Shanghai; region 3 includes Liaoning, Jilin and Heilongjiang; region 4 includes Jiangsu, Zhejiang, Jiangxi and Hubei; region 5 includes Fujian, Hunan, Guangdong, Guangxi and Hainan; region 6 includes Chongqing, Sichuan, Shaanxi, Gansu, Guizhou and Yunnan; region 7 includes Mongolia, Tibet (data unavailable), Qinghai, Ningxia and Xinjiang.

Table 7

The Change of Energy Efficiency from 1995 to 2002

Year	Average	East	Central	West
		Total Factor Energy Efficiency		
1995	64.1	74.6	49.4	64.1
1996	65.8	76.0	53.5	61.7
1997	65.2	75.1	52.4	62.8
1998	65.6	75.1	53.3	62.8
1999	67.7	77.6	53.9	65.6
2000	66.4	76.8	52.0	63.1
2001	72.7	81.7	62.7	65.9
2002	76.0	83.6	68.2	69.1
Mean	67.9	77.6	55.7	64.4
		Partial Factor Energy Efficiency–the Energy Productivity Ratio		
1995	45.3	62.5	37.2	28.7
1996	46.6	62.6	40.7	29.1
1997	46.8	62.2	41.9	29.2
1998	46.4	61.2	42.5	28.4
1999	44.9	58.8	41.3	28.0
2000	43.9	57.0	40.4	28.1
2001	42.2	54.6	39.0	27.2
2002	39.6	51.5	36.4	25.5
Mean	44.5	58.8	39.9	28.0

Note: The numbers of this table come from table 4 and table 5 of Hu and Wang (2006).

Table 8

International Comparison of Implied Elasticities of Substitution (σ_{ij}) and Price Elasticities (η_{ij}) of Factor Demand for Aggregate Economy

	China (1995-04)	South Korea (1981-97)	West Germany (1976-94)	Greece (1970-90)	Portugal (1980-96)	Spain (1980-96)
σ_{EE}	-1.723	4.850	-	-	-3.73	-0.729
σ_{EK}	0.803	0.783	-0.399	0.972	0.893	-0.012
σ_{EL}	0.613	-1.418	-0.075	0.976	0.812	0.300
σ_{KK}	-3.034	-1.111	-	-	-0.299	-0.275
σ_{KL}	0.338	0.867	-	1.061	-0.134	0.952
σ_{LL}	-0.365	-0.556	-		-0.219	-1.043
η_{EE}	-0.472	0.356	-	-0.845	-0.689	-0.122
η_{EK}	0.111	0.341	-0.320	0.361	0.301	-0.005
η_{EL}	0.361	-0.697	0.867	0.236	0.388	0.127
η_{KE}	0.220	0.058	-0.133	0.060	0.165	-0.002
η_{KK}	-0.419	-0.484	-	-0.436	-0.101	-0.400
η_{KL}	0.199	0.426	-	0.386	-0.064	0.402
η_{LE}	0.168	-0.104	0.191	0.058	0.150	0.050
η_{LK}	0.047	0.377	-	0.565	-0.045	0.391
η_{LL}	-0.215	-0.277	-	-0.604	-0.105	-0.441

Note: E stands for aggregate energy, K stands for capital and L stands for labor. Numbers are in parentheses are the standard errors. The elasticities of South Korea are from Cho, Nam and Pagan (2004) and those of West Germany are from Welsch and Ochsen (2005). Manufacturing for Greek,

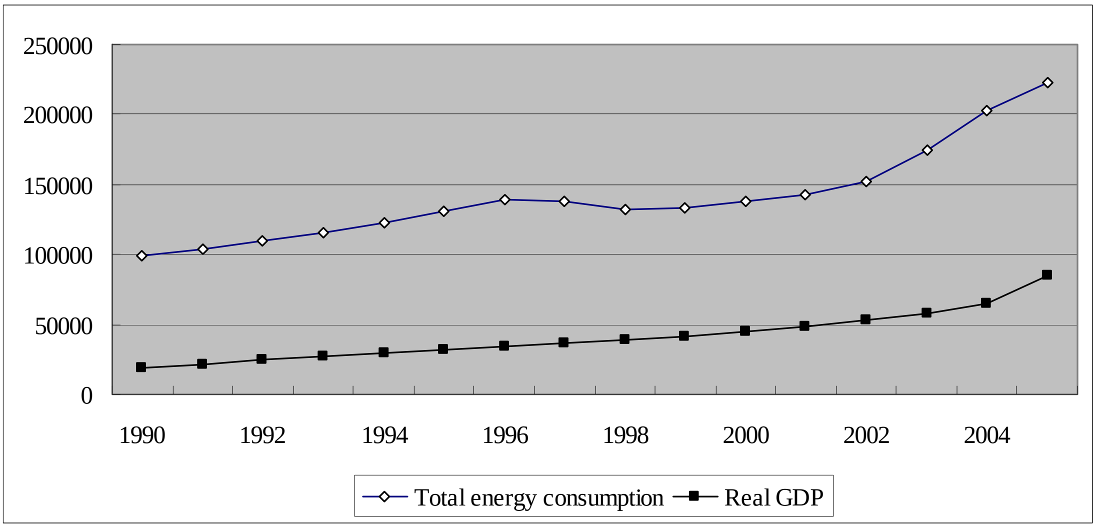

Figure 1. Relationship between total energy consumption and real GDP of China
Note: Total energy consumption is measured in 10000 metric tons standard coal equivalent and real GDP is measured in 100 million RMB.

Table A1

The Estimates of Total Factor Cost Function for *Industry* Energy Demand

Variable	Coeff.	t-stat.	Variable	Coeff.	t-stat.	Variable	Coeff.	t-stat.
P_E	0.287	3.62	P_LD4	-0.991	-5.42	P_EtD3	-0.003	-0.79
P_K	0.287	4.54	P_LD5	0.024	0.09	P_EtD4	-0.001	-0.42
P_L	0.426	4.38	P_LD6	-0.004	-0.03	P_EtD5	0.004	1.28
P_EP_E	0.070	3.62	YD1	5.359	1.23	P_EtD6	0.008	2.64
P_EP_K	-0.007	-0.42	YD2	-8.549	-2.93	P_KtD1	-0.015	-4.84
P_EP_L	-0.062	-3.70	YD3	-3.149	-2.39	P_KtD2	-0.023	-7.59
P_KP_K	0.061	2.48	YD4	0.434	0.64	P_KtD3	-0.006	-2.20
P_KP_L	-0.054	-3.31	YD5	-4.762	-5.46	P_KtD4	0.003	1.24
P_LP_L	0.116	5.20	YD6	1.853	1.44	P_KtD5	-0.002	-0.94
Y	0.628	0.96	tD1	-0.541	-1.41	P_KtD6	-0.003	-1.28
YY	0.025	0.29	tD2	0.651	2.31	P_LtD1	0.014	2.92
P_EY	-0.009	-0.87	tD3	0.190	1.18	P_LtD2	0.018	3.88
P_KY	-0.021	-2.60	tD4	0.002	0.02	P_LtD3	0.008	2.08
P_LY	0.030	2.40	tD5	0.370	3.61	P_LtD4	-0.002	-0.46
t	0.050	0.60	tD6	-0.136	-0.99	P_LtD5	-0.002	-0.44
tt	0.003	0.81	P_EYD1	0.040	1.90	P_LtD6	-0.005	-1.33
P_Et	0.010	4.59	P_EYD2	-0.035	-1.60	YYD1	-0.769	-1.25
P_Kt	-0.001	-0.38	P_EYD3	0.091	5.89	YYD2	1.201	2.99
P_Lt	-0.009	-3.54	P_EYD4	0.049	4.06	YYD3	0.411	2.35
Yt	-0.013	-1.18	P_EYD5	-0.052	-3.61	YYD4	-0.038	-0.42
P_ED1	-0.233	-1.56	P_EYD6	-0.032	-2.52	YYD5	0.667	5.52
P_ED2	0.269	1.63	P_KYD1	0.049	2.96	YYD6	-0.324	-1.51
P_ED3	-0.704	-5.88	P_KYD2	0.195	11.0	ttD1	-0.004	-0.48
P_ED4	-0.360	-3.93	P_KYD3	0.052	4.21	ttD2	0.008	1.14
P_ED5	0.358	3.43	P_KYD4	-0.022	-2.29	ttD3	0.012	1.95
P_ED6	0.189	2.09	P_KYD5	0.029	2.49	ttD4	-0.002	-0.46
P_KD1	-0.168	-1.41	P_KYD6	0.017	1.72	ttD5	0.007	1.46
P_KD2	-1.327	-10.1	P_LYD1	-0.089	-3.48	ttD6	-0.007	-1.22
P_KD3	-0.377	-3.96	P_LYD2	-0.159	-5.88	YtD1	0.079	1.48
P_KD4	0.150	2.07	P_LYD3	-0.143	-7.56	YtD2	-0.096	-2.47
P_KD5	-0.212	-2.54	P_LYD4	-0.027	-1.83	YtD3	-0.036	-1.62
P_KD6	-0.075	-1.04	P_LYD5	0.023	1.32	YtD4	0.005	0.38
P_LD1	-0.117	-0.34	P_LYD6	0.015	0.94	YtD5	-0.055	-3.81
P_LD2	1.229	5.37	P_EtD1	0.001	0.33	YtD6	0.027	1.22
P_LD3	2.350	7.15	P_EtD2	0.005	1.31			

Note: All indices are measured in term of natural logarithm, P and Y represent price and output, and D represents regions. Regional dummy variables and constant term are not shown in the table.

Table A2

The Estimates of *Fuel* Share Equations for *Industry* Energy Demand

Coal			Electricity			Oil		
Variable	Coeff.	t-stat.	Variable	Coeff.	t-stat.	Variable	Coeff.	t-stat.
Cons	0.269	22.42	Cons	0.639	49.15	Cons	0.092	11.50
D1	-0.081	-3.24	D1	0.088	3.26	D1	-0.007	-0.41
D2	0.004	0.16	D2	-0.022	-0.81	D2	0.018	1.06
D3	-0.025	-1.09	D3	0.008	0.33	D3	0.016	1.07
D4	-0.036	-1.71	D4	0.030	1.36	D4	0.007	0.50
D5	-0.030	-1.50	D5	0.037	1.76	D5	-0.007	-0.54
D6	-0.140	-6.09	D6	0.098	4.08	D6	0.043	2.87
P1	0.039	2.17	P1	-0.013	-0.72	P1	-0.026	-2.17
P2	-0.013	-0.72	P2	0.051	2.13	P2	-0.037	-2.06
P3	-0.026	-2.17	P3	-0.037	-2.06	P3	0.063	2.86
t	-0.008	-4.00	T	0.011	5.50	t	-0.004	-4.00
tD1	0.000	0.00	tD1	-0.002	-0.50	tD1	0.002	0.67
tD2	-0.007	-1.75	tD2	0.006	1.20	tD2	0.001	0.33
tD3	-0.003	-0.75	tD3	0.006	1.50	tD3	-0.003	-1.50
tD4	-0.003	-1.00	tD4	0.000	0.00	tD4	0.003	1.50
tD5	0.000	0.00	tD5	-0.001	-0.33	tD5	0.001	0.50
tD6	0.014	3.50	tD6	-0.009	-2.25	tD6	-0.005	-2.50

Note: Coefficients for oil share are calculated based on adding-up restriction. Prices are measured in term of logarithm.

Table A3

Implied Elasticities of Substitution (σ_{ij}) and Price Elasticities (η_{ij}) of Demand for the Interfactor Substitution for *Industry* Economy

	Elasticities	Standard Error
σ_{EE}	-0.8367^{**}	0.1512
σ_{EK}	0.6706^{**}	0.2522
σ_{EL}	0.5144^{**}	0.1789
σ_{KK}	-2.0753^{**}	0.3596
σ_{KL}	0.6786^{**}	0.2551
σ_{LL}	-1.0900^{**}	0.1532
η_{EE}	-0.3423^{**}	0.0619
η_{EK}	0.1644^{**}	0.0529
η_{EL}	0.1778^{**}	0.0372
η_{KE}	0.2743^{**}	0.0882
η_{KK}	-0.5089^{**}	0.1041
η_{KL}	0.2346^{**}	0.0681
η_{LE}	0.2104^{**}	0.0440
η_{LK}	0.1664^{**}	0.0483
η_{LL}	-0.3768^{**}	0.0530

Note: E stands for aggregate energy, K stands for capital and L stands for labor. Elasticities are calculated with mean of each share. S_E=0.4091, S_K=0.2452 and S_L=0.3457.

Table A4

Implied Elasticities of Substitution (σ_{ij}) and Price Elasticities (η_{ij}) of Fuel Demand for the Interfuel Substitution of *Industry* Economy

	Elasticities	Standard Error		Elasticities	Standard Error
σ_{CC}	-3.1360**	0.4866	η_{CC}	-0.6046**	0.0938
σ_{CE}	0.9030**	0.1273	η_{CE}	0.1741*	0.0909
σ_{CO}	-0.4283	0.6925	η_{CO}	-0.0826	0.0647
σ_{EE}	-0.3013**	0.0473	η_{EC}	0.6446**	0.0245
σ_{EO}	0.4383	0.2774	η_{EE}	-0.2150**	0.0337
σ_{OO}	-2.4646	2.5169	η_{EO}	0.3128**	0.0259
			η_{OC}	-0.0400	0.1335
			η_{OE}	0.0409	0.1980
			η_{OO}	-0.2303	0.2352

Note: C stands for coal, E stands for electricity and O stands for oil. Elasticities are calculated with mean of each share. S_C=0.1928, S_E=0.7138 and S_O=0.0934.

Table A5

Total Implied Fuel-Price Elasticities (η_{ij}^{*}) for the Interfuel Substitution of *Industry* Economy

	Elasticities
η_{CC}^{*}	-0.6730
η_{CE}^{*}	0.1057
η_{CO}^{*}	-0.1510
η_{EC}^{*}	0.3913
η_{EE}^{*}	-0.4683
η_{EO}^{*}	0.0595
η_{EC}^{*}	-0.0732
η_{EE}^{*}	0.0078
η_{EO}^{*}	-0.2634

Note: C stands for coal, E stands for electricity and O stands for oil. Elasticities are calculated with mean of each share. S_C=0.1928, S_E=0.7138 and S_O=0.0934.

Table A6

Decomposition of the Change in Energy Intensity for *Industry* Economy

Region	$\Delta\hat{e}/\hat{e}$	Budget	Substitution				GDP	Tech.
			Sum	Energy	Capital	Labor		
National	0.0685	-0.1012	-0.0140	0.0539	0.0009	-0.0689	-0.0124	0.1961
Region 1	0.0231	-0.1455	0.0152	0.0639	0.0018	-0.0505	-0.0308	0.1842
Region 2	0.0720	-0.0791	-0.0465	0.0523	0.0032	-0.1021	-0.0061	0.2037
Region 3	-0.0954	-0.2176	-0.0132	0.0857	0.0002	-0.0991	-0.0522	0.1877
Region 4	0.1315	-0.0436	-0.0263	0.0295	0.0020	-0.0578	0.0047	0.1968
Region 5	0.0861	-0.0887	-0.0146	0.0399	0.0037	-0.0582	-0.0075	0.1969
Region 6	0.0685	-0.1012	-0.0140	0.0539	0.0009	-0.0689	-0.0124	0.1961
Region 7	0.0639	-0.1238	-0.0088	0.0721	-0.0021	-0.0788	-0.0069	0.2034

Note: Region 1 includes Hebei, Shanxi, Anhui, Shandong and Henan; region 2 includes Beijing, Tianjin, and Shanghai; region 3 includes Liaoning, Jilin and Heilongjiang; region 4 includes Jiangsu, Zhejiang, Jiangxi and Hubei; region 5 includes Fujian, Hunan, Guangdong, Guangxi and Hainan; region 6 includes Chongqing, Sichuan, Shaanxi, Gansu, Guizhou and Yunnan; region 7 includes Mongolia, Tibet (data unavailable), Qinghai, Ningxia and Xinjiang.

Table A7

Maximum Likelihood Ratio Tests for the Separability and Incorporation of Regional Dummy Variables

Variables	Critical Values		# Restrictions	χ^2 Statistics	
	5%	1%		Aggregate	Industrial
Factor Cost Function:					
$\sum P_i D_k$	27.6	33.4	17	344.4^{**}	292.3^{**}
$\sum P_i t$ and $\sum D_k P_i t$	23.7	29.1	14	231.4^{**}	202.1^{**}
$\sum D_k P_i t$	21.0	26.2	12	104.7^{**}	90.2^{**}
$\sum P_i P_j$	7.8	11.3	3	35.0^{**}	39.4^{**}
$\sum D_k y$ and $\sum D_k yy$	21.0	26.2	12	122.3^{**}	149.7^{**}
$\sum D_k t$ and $\sum D_k tt$	21.0	26.2	12	49.7^{**}	104.8^{**}
$\sum D_k yt$	12.6	16.8	6	48.2^{**}	104.0^{**}
$\sum D_k$	12.6	16.8	6	86.7^{**}	141.7^{**}
Aggregate Energy Price Function:					
$\sum p_j D_k$	28.9	34.8	18	116.1^{**}	50.2^{**}
$\sum p_j t$ and $\sum D_k p_j t$	28.9	34.8	18	84.1^{**}	60.3^{**}
$\sum D_k p_j t$	25.0	30.6	15	32.4^{**}	19.0
$\sum p_i p_j$	12.6	16.8	6	38.4^{**}	11.6^{**}

Note: The null hypotheses related to any two of price, output and time variables are the separability; the null hypotheses for regional dummy variables are there are no significant differences in production behaviour across regions.