Modelling Energy Consumption in China

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Abstract: Energy consumption in China has attracted considerable research interest since the middle 1990s. This is largely prompted by the environmental ramifications of the extensive use of fossil fuels in the country to propel two decades of high economic growth. Since the late 1980s, there has been an increasing awareness on the part of the Chinese government of the imperative for the balance of economic growth and environmental protection. The government has since taken various measures ranging from encouraging energy-saving practice, controlling waste discharges to financing R & D programs on improving energy efficiency. Against this backdrop has seen a constant decline of the energy intensity of the economy, measured as the ratio of total energy consumed in standard coal equivalent to the real GDP since 1989. Using the 1987 and 1997 input-output tables for China, the present study examines the impact of technical and structural changes in the economy on industry fuel consumption over the 10-year period. Technical changes are reflected in changes in direct input-output coefficients, which capture the technical evolvement of intermediate production processes. Structural changes refer to shifts in the pattern of final demand for energy, including the import and export composition of various fuels. Six fuels are included in the study, namely, coal, oil, natural gas, electricity, petroleum and coke and gas, which cover all of the energy types available in the input-output tables. It is found that the predominant force of falling energy intensity was changes in direct energy input requirements in various industries. Such changes were responsible for a reduction in the consumption of four of the six fuels per unit of total output. Structural changes were not conducive for improving energy efficiency. These findings are consistent with previous studies, which used shorter timeframes of data. However, unlike the previous studies, technical changes are differentiated between direct and total input requirements. This allows the separation of the impacts on energy use of energy-saving technologies in the production process and of the externalities of such technologies due to input-output linkages.

Keywords: energy intensity; input-output tables; technical changes; structural changes.

1. INTRODUCTION

Energy consumption in China has attracted considerable research interest since the middle 1990s. This is largely prompted by the environmental ramifications of the extensive use of fossil fuels in the country to propel two decades of high economic growth. Since the late 1980s, there has been an increasing awareness on the part of the Chinese government of the imperative for the balance of economic growth and environmental protection. The government has since taken various measures ranging from encouraging energy-saving practice, controlling waste discharges to financing R & D programs on improving energy efficiency. Against this backdrop has seen a constant decline of the energy intensity of the economy, measured as the ratio of total energy consumed in standard coal equivalent to the real GDP since 1989. Using the 1987 and 1997 input-output tables for China, the present study examines the impact of technical and structural changes in the economy on industry fuel consumption over the 10-year period. Technical changes are reflected in changes in direct input-output coefficients, which capture the technical evolvement of intermediate production processes. Structural changes refer to shifts in the pattern of final demand for energy, including the import and export composition of various fuels. Six fuels are included in the study, namely, coal, oil, natural gas, electricity, petroleum and coke and gas (CG), which cover all of the energy types available in the input-output tables. It is found that the predominant force of falling energy intensity was changes in direct energy input requirements in various industries. Such changes were responsible for a reduction in the consumption of four of the six fuels per unit of total output. Structural changes were not conducive for improving energy efficiency. These findings are consistent with previous studies, which used shorter timeframes of data.

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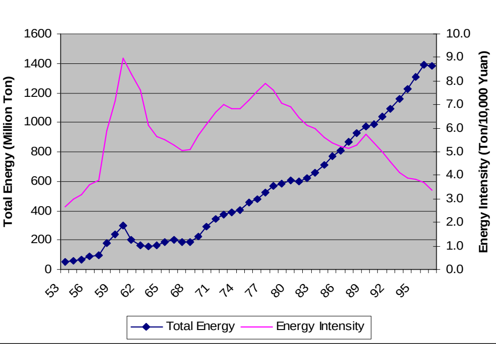

Figure 1. Total energy and energy intensity

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Table 1. China's Energy Balance by Major Fuel Type:

Total Domestic Production-Total Domestic Consumption

Year	Total	Coal	Oil	Natural Gas	Hydro-power
1985	8,864.0	4,152.5	4,766.5	23.9	-78.9
1986	7,274.0	2,517.5	4,776.1	-8.9	-10.6
1987	4,634.0	245.5	4,438.4	6.0	-56.0
1988	2,804.0	-833.2	3,733.9	-36.9	-59.8
1989	4,705.0	1,644.7	3,040.6	94.1	-74.4
1990	5,219.0	1,898.4	3,360.5	5.7	-45.6
1991	1,061.0	-1,289.5	2,383.2	21.2	-53.9
1992	-1,914.0	-2,950.5	1,166.6	70.9	-201.0
1993	-4,934.0	-4,463.1	-342.7	17.3	-145.5
1994	-4,008.0	-3,480.9	-459.9	-76.2	9.0
1995	-2,142.0	-694.7	-1,536.2	90.5	-1.6
1996	-6,332.0	-4,066.9	-2,465.9	151.3	49.6
1997	-5,763.0	-3,176.5	-2,660.8	5.6	68.7

Unit: 10,000 ton of SCE (Standard Coal Equivalent)

The plan of the paper is as follows. A snapshot of China's energy consumption is included in Section 2, whereby the growth rate of energy use and the balance of domestic production and consumption of energy are presented. Section 3 depicts the input-output analytical framework, and Section 4 discusses the data and empirical results. Finally, some concluding remarks are contained in Section 5.

2. A SNAPSHOT OF ENERGY CONSUMPTION

Energy consumption in China has predominantly comprised of uses of fossil fuels, particularly, coal. However, the share of coal consumption in China's total energy consumption over the 10 years to 1997 had declined by about 3 per cent. This compares with an increase of nearly 6 per cent over the preceding 10-year period. The time series paths of total energy consumption and energy intensity are depicted in Figure 1. While total energy consumption has risen continuously, energy intensity has been falling since 1978 except for 1988 and 1989 when a slight rise was recorded. Energy intensity rose sharply during the late 1950s when Great Leap Forward movement took place. Although the energy intensity of the economy was improving over the 20 years or so to 1997, the continuous rise of total energy consumption had implications on both domestic energy production and international energy markets. Table 1 presents domestic production and consumption of four primary fuels, namely, coal, oil, natural gas and hydro-power. Electricity generated by coal-firing is included in coal. These four types of fuel comprise total energy use in the country. As shown in the table, China's energy consumption started to exceed domestic energy production in the early 1990s when the economy entered an accelerated growth period.

As energy consumption increasingly exceeds domestic energy production, China has turned from an energy-exporting country to an energy-importing country. As Table 1 shows, the 1992 total energy consumption was in "deficit" by about 19 million tons of SCE. This grew to 58 million tons of SCE in 1997. Although coal consumption exceeded coal production by 20 million tons of SCE over the period 1991 to 1997, the gap was not responsible for surging energy imports as it was filled by coal stocks. The predominant contributing factor was the import of crude oil and petroleum products. Over the 7 years, a net import of 5.1 million tons of crude oil and petroleum products was recorded.

Of the six broad sectors, namely, Agriculture, Industry, Construction, Transportation, Post and

Telecommunications, Commerce, Household and Others, the industry and household sectors accounted for 84 per cent of total energy consumed in 1997, with 72 per cent attributable to the former. The industry sector consists of mining, manufacturing and production of electricity, gas and water, with the manufacturing sub-sector contributing 78 per cent of its total energy consumption. The chemical and metal products industries were the largest consumers of energy and responsible for over 40 per cent of total manufacturing energy consumption.

3. ANALYTICAL FRAMEWORK

The input-output modelling technique has been extensively used in decomposition analyses of sectoral energy consumption. This is mainly because an input-output table conveniently presents an exact quantitative relationship between the energy sector and its users. Some recent studies in this regard include Mukhopadhyay and Chakraborty (2002), Kagawa and Inamura (2001), Garbaccio et al (1999), Hudson and Jorgenson (1998), Rose (1999), Chen and Rose (1990), and Lin and Polenske (1995). The Garbaccio et al and Lin and Polenske studies focus on China's energy consumption in general and energy intensity in particular. Both studies used latest available SNA input-output tables from China, with the 1995 one for the Garbaccio study and the 1987 one for the Lin and Polenske study. All of them found technical changes to be the major source of energy intensity decline.

The input-output model for an economy with n industries can be written as,

$$\underset{n\times 1}{Q} = \underset{n\times n}{A} * \underset{n\times 1}{Q} + \underset{n\times k}{F} * \underset{k\times 1}{\mathrm{i}} \qquad (1)$$

or,

$$\underset{n\times 1}{Q} = (I - \underset{n\times n}{A})^{-1} * \underset{n\times k}{F} * \underset{k\times 1}{\mathrm{i}} = R * F * \mathrm{i}$$

where the element in the *ith* row in Q, q_i, represents the total output of industry i; the element in the *ith* row and *jth* column in A, a_{ij}, represents the amount of q_j required to produce a unit of q_i; and the element in the *ith* row and *jth* column in F, f_{ij}, represents the *jth* category of the final demand for the *ith* industry; and i is the unit vector.

Suppose m of the n industries belong to the energy sector. The rows (output by industry) and the columns (input by industry) in equation (1) can swap positions so that the energy industries and non-energy industries can be grouped in blocks, that is,

$$Q = \begin{pmatrix} \underset{m\times 1}{Q^{E}} \\ \underset{(n-m)\times 1}{Q^{NE}} \end{pmatrix} = \begin{pmatrix} \underset{m\times n}{A^{E}} \\ \underset{(n-m)\times n}{A^{NE}} \end{pmatrix} * Q + F * \mathrm{i} \qquad (2)$$

In equation (2), A^E characterises the production technology governing intermediate energy requirements by both the energy and non-energy sectors. Therefore, the total energy consumption (output) can be expressed in terms of the input-output coefficients and final demand as the following:

$$Q^E = (A^E * R + \mathbf{J}) * F * \mathbf{i} = B * F * \mathbf{i} \qquad (3)$$

where $\mathbf{J} = [\mathbf{I}_m \;\; \mathbf{0}_{m\times(n-m)}]$.

Adding time subscripts to the above equation, one can decompose the change of energy consumption between two time periods, t and s, as below.

$$\begin{aligned} Q_t^{E} - Q_s^{E} &= (A_t^{E} - A_s^{E}) * R_t * F_t * \mathbf{i} \\ &+ A_s^{E} * (R_t - R_s) * F_t * \mathbf{i} \\ &+ B_s * (F_t - F_s) * \mathbf{i} \end{aligned} \qquad (4)$$

The three items on the right-hand side of equation (4) measure the change of energy consumption due to changes in technologies governing intermediate energy requirements (direct energy input requirements), changes in total input requirements, and changes in final demand, respectively.

4. Data and Empirical Results

The data for the present study are China's 1987 and 1997 input-output tables. The 1987 one is China's first input-output table compiled based on the SNA system, which has been adopted for compiling subsequent input-output tables. The 1997 one is the latest available input-output table.

The industries in the input-output tables are aggregated into 6 energy sectors/products, namely, coal, crude oil, natural gas, electricity, petroleum, and CG, and 18 non-energy sectors. The sectors and their shares of energy consumption are listed in Table 2. It is clear that the relativity of the shares of sectoral energy consumption has barely changed over the 10 years; Metal Products, Chemical, Residential, and Building Materials remain the top four energy consumers. This suggests that the decline of energy intensity of the economy could not be caused by industry structural change. The fact that the residential sector accounts for a prominent share of total energy consumption gives rise to the importance of final demand in driving the energy demand of the economy.

The data in the 1987 input-output table are re-based on 1997 prices using ex-factory price indices of industrial products for the 1988-1997 period (source: China Statistical Yearbook 1998, China Statistical Yearbook 1994).

Table 2. Shares of Total Energy Consumption

Sector	% of Total SCE	
	1987	1997
Coal	3.96	4.19
Crude Oil	1.78	2.55
Natural Gas	0.12	0.03
Electricity	3.43	7.29
Petroleum	1.42	3.21
Coking and Gas	1.05	2.45
Agriculture	5.16	4.27
Mining	1.68	1.16
Foodstuff	3.35	2.78
Textile	3.07	2.55
Timber and Paper	1.08	1.95
Other manufacturing	2.97	1.36
Chemical	12.57	13.95
Building Materials	10.68	8.91
Metal Products	15.67	16.28
Machinery	5.05	3.76
Construction	1.45	0.85
Transport. and Telecom.	4.76	5.46
Commerce	1.05	1.73
Residential	16.53	11.85
Other Services	3.18	3.40

The increases of the consumption of the six fuels over the period 1987-1997 is analysed in Table 3. In particular, the increases are decomposed into the three parts described in equation (4).

Since the total output of the economy has increased more than 15 times from 1987 to 1997 (calculated based on the two input-output tables), it is not surprising that the 10-year period has seen the gigantic leaps of fuel consumption for all the 6 fuels.

The changes in direct energy input requirements, $(A_{1997}{}^{E} - A_{1987}{}^{E})$, have resulted in energy savings for all the fuels except Natural Gas and CG. The most significant saving has occurred for crude oil and petroleum products, followed by coal. This outcome is attributable to recent practice in China. Since the early 1990s, China has been alarmed by the shortage of oil to fuel its economy and by the deterioration of its environment. Various measures have since been implemented, which amount to increasing the efficiency of using oil products and curbing coal consumption.

Since the changes in direct energy input requirements were conducive to bringing down total energy consumption, they must also reduce energy intensity. This is because the elements in A^{E} are measured as the energy cost per unit of total output, and their changes that have led to a reduction in total energy consumption have necessarily resulted in a reduction in energy intensity for a given level of total output.

Compared with direct energy input requirements, total input requirements include both energy and non-energy inputs for intermediate production as well as final consumption. Hence, changes in total input requirements reflect changes in the inter-industry relationships or the structure of the economy. Over the period under study, such changes, $(R_{1997} - R_{1987})$, have generally increased fuel consumption, with a fuel reduction only recorded for crude oil.

In contrast, changes in total input requirements will generally cause changes in not only energy consumption, as described by $A_s{}^{E} * (R_t - R_s) * F_t * \mathbf{i}$, but also total output, as described by $(R_t - R_s) * F_t * \mathbf{i}$. Such changes can either increase or decrease energy intensity, depending on if

$$\frac{W^{E} * A_s{}^{E} * (R_t - R_s) * F_t * \mathbf{i}}{\mathbf{i}' * (R_t - R_s) * F_t * \mathbf{i}} > \frac{W^{E} * A_s{}^{E} * R_s * F_s * \mathbf{i}}{\mathbf{i}' * R_s * F_s * \mathbf{i}}$$

or otherwise. The W^E in the above inequality contains fuel conversion factors and is conformably dimensioned so that the numerator equals total energy consumed. In the present study, the left-hand-side of the inequality is the impact on the energy intensity in 1997 of changing total input requirements, whereas the right-hand-side of the inequality represents the energy intensity in 1987. Evaluating the inequality using the two input-output tables (in 1997 prices) gives 0.36 and 1.01 tons of SCE per ten-thousand Yuan of output for the two quantities, respectively. This implies that the newly increased output consumed less energy than the same amount of output would have consumed had the total input requirements remained unchanged. The net outcome is the abatement of energy intensity in 1997.

The third source of change for energy consumption is final demand. Unlike the other two factors, increases in final demand amount to augmenting the scale of an economy, which ought to lead to increases in energy consumption *ceteris paribus*. The increases in final demand, $(F_{1997} - F_{1987})$, have led to increases in energy consumption across the board. Crude oil has been affected most; the increment of its consumption has largely outweighed the savings accrued by the other two factors.

However, final demand changes entail changes in the level as well as in the composition, which may have different effects on energy consumption. To distinguish these two types of effects, $(F_{1997} - F_{1987})$, is to be further decomposed.

In the present study, four components of final demand are considered, namely, total final consumption, total investment, the balance of trade and *Other*. The *Other* category was created by China's State Statistical Bureau to accommodate residuals in order to make input-output tables balanced.

To quantify the effects of compositional changes in final demand on energy consumption, the growth rate of each final demand component is calculated first. Then, the individual growth rates are averaged for each industry.

Let G be a diagonal $n \times n$ matrix containing the average growth rates of various final demand components for all n industries. The compositional and level changes in final demand are then represented by $[F_{1997} - (I+G)*F_{1987}]$ and $[(I+G)*F_{1987} - F_{1987}] = G*F_{1987}$, respectively, with the sum of the two equal to the overall changes in final demand.

$(I+G)*F_{1987}$ assumes that every component of final demand for a particular product or industry grew constantly between 1987 and 1997. Taking into account the overall growth of final demand, $[F_{1997} - (I+G)*F_{1987}]$ shows changes in final demand merely caused by varied growth of the components, namely, compositional changes. Similarly, $[(I+G)*F_{1987} - F_{1987}]$ reflects only level changes as the composition of final demand is assumed unchanged over the course 1987-1997.

The effects of the two types of change on energy consumption are presented on the two rows labelled $B_{1987}*[F_{1997} - (I+G)*F_{1987}]*\mathbf{i}$ and $B_{1987}*[(I+G)*F_{1987} - F_{1987}]*\mathbf{i}$ in Table 3, respectively. The compositional changes in final demand have resulted in savings in coal and CG consumption, whereas the level changes have dampened electricity consumption. However, none of the changes have reduced the consumption of crude oil and petroleum products, the two largest components in China's imports of energy.

Similarly, changes in final demand cause changes in total output which, in turn, consumes more energy. Therefore, final demand changes will raise energy intensity if the inequality below holds,

$$\frac{W^E * A_s^E * R_s * (F_t - F_s) * \mathbf{i}}{\mathbf{i}' * R_s * (F_t - F_s) * \mathbf{i}} > \frac{W^E * A_s^E * R_s * F_s * \mathbf{i}}{\mathbf{i}' * R_s * F_s * \mathbf{i}}$$

Evaluating the left-hand side of the expression gives 2.3 tons of SCE per ten-thousand Yuan of output, which points to a worsening in energy intensity.

5. CONCLUDING REMARKS

Using the 1987 and 1997 input-output tables from China, the present study has analysed the source of energy use changes over the period 1987-1997. In particular, three such sources have been investigated, namely, direct energy input requirements, total input requirements and final demand. It is found that the changes in direct energy input requirements are the most significant source of energy consumption decline and hence energy intensity decline. The changes in total input requirements have led to increases in both total output and energy consumption, but the increases in the latter have been slower than the former, which resulted in a reduction in energy intensity. Finally, final demand changes have worked against energy savings in general and increased energy intensity.

6. ACKNOWLEDGEMENT

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Table 3. Decomposition of Energy Consumption: 1987-1997 unit: million Yuan

	Coal	Crude Oil	Natural Gas	Electricity	Petroleum	CG
$Q_{1997}{}^{E}$	2,227,479.1	1,075,013.5	556,381.0	3,908,709.3	2,183,769.5	1,053,919.4
$Q_{1987}{}^{E}$	110,206.2	146,241.1	9,980.4	155,268.3	214,619.4	30,032.0
$Q_{1997}{}^{E} - Q_{1987}{}^{E}$	2,117,272.9	928,772.4	546,400.6	3,753,441.0	1,969,150.1	1,023,887.4
Subdivided into						
$(A_{1997}{}^{E} - A_{1987}{}^{E}) * R_{1997} * F_{1997} * \mathbf{i}$	-530,947.0	-432,256.2	308,080.8	-434,822.1	-2,435,089.5	280,362.8
$A_{1987}{}^{E} * (R_{1997} - R_{1987}) * F_{1997} * \mathbf{i}$	420,379.0	-681,886.1	103,270.9	667,286.0	518,882.6	21,230.7
$B_{1987} * (F_{1997} - F_{1987}) * \mathbf{i}$	2,227,840.8	2,042,914.8	135,048.9	3,520,977.1	3,885,357.0	722,293.9
Subdivided into						
$B_{1987} * [F_{1997} - (I+G) * F_{1987}] * \mathbf{i}$	-2,153,179.7	1,278,989.2	13,196.6	4,872,921.3	2,247,232.8	-115,565.1
$B_{1987} * [(I+G) * F_{1987} - F_{1987}] * \mathbf{i}$	4,381,020.5	763,925.6	121,852.3	-1,351,944.2	1,638,124.3	837,859.1
Proportions of increase (%)						
$(A_{1997}{}^{E} - A_{1987}{}^{E}) * R_{1997} * F_{1997} * \mathbf{i}$	-25.1	-46.5	56.4	-11.6	-123.7	27.4
$A_{1987}{}^{E} * (R_{1997} - R_{1987}) * F_{1997} * \mathbf{i}$	19.9	-73.4	18.9	17.8	26.4	2.1
$B_{1987} * (F_{1997} - F_{1987}) * \mathbf{i}$	105.2	220.0	24.7	93.8	197.3	70.5