An Analysis of Energy Intensity in China

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Abstract: The energy intensity of the Chinese economy, measured as the ratio of total energy consumed in standard coal equivalent to real GDP, has been declining continuously since 1989. While various studies have been carried out to explain factors driving China's energy consumption, only a few studies have focused on modelling the causes of China's decline in energy intensity. The study of Fisher-Vanden et al (2004) used the regression approach to modelling energy intensity based on sample data collected on a large number of industrial enterprises. With two most recent input-output tables at the time, Garbaccio et al (1999) employed the input-output approach to constructing an index on energy intensity. Fisher-Vanden et al found that production structure changes were one of the major factors causing the decline in energy intensity, whereas the study of Garbaccio et al pointed to technological changes being responsible for the decline in energy intensity. A direct comparison between the two studies can be difficult as production structural changes were not explicitly considered in the study of Garbaccio et al. However, the technological changes considered by Garbaccio et al were measured using the Leontief inverse which is a function of direct input-output coefficients reflecting the production process. Therefore, both studies have implied the importance of the production process in determining energy intensity for the whole economy. Nevertheless, they both have ignored that the underlying factors for the production process to impact on overall energy intensity are energy intensities of various productive industries. Since more than 90 per cent of total energy consumption takes place in the intermediate production in China, it is particularly important to study how industry energy intensities in the intermediate production and the interactions of them dictate the energy intensity for the whole economy.

In the input-output framework, technological advances in energy conservation that result in a decline in energy intensity in an industry will be recorded as a fall in direct input-output coefficients in the row for the energy sector. Such a fall/rise indicates that energy intensities of various industries in the production process have declined/increased. The present study focuses on the impact of such changes on overall energy intensity. In particular, the Elasticity Coefficient Analysis method due to Schnabl (2003) is adopted to devise a new method to decompose changes in overall energy intensity. It is shown that changes in overall energy intensity is comprised of changes in the technology that governs the linkage between energy intensities in the production process and final consumption, changes in the magnitude of energy intensities in the production process, and changes in final consumption composition. This method is then applied to the 1987 and 1997 Chinese input-output tables to quantify the impact of energy intensities of 13 productive sectors on the overall energy intensity. Of particular interesting is the finding that although for two sectors

there had been an increasing in the magnitude of energy intensity in the production process during the 10-year period, they contributed to the reduction in the overall energy intensity thanks to changes in the technology linking energy intensities in the production process and final consumption. This result is consistent with the findings in Fisher-Vanden et al.

Keywords: overall energy intensity, energy intensity in intermediate production, energy intensity in final consumption, technology.

1. Introduction

It is widely reported that the energy intensity of the Chinese economy, measured as the ratio of total energy consumed in standard coal equivalent to real GDP, has been declining continuously since 1989. The time series paths of total energy consumption and total energy intensity are depicted in Figure 1. Total energy intensity was computed by dividing the national total energy consumption (in standard coal equivalent) by the national GDP. While total energy consumption has risen continuously, total energy intensity has been falling since 1978 except for 1988 and 1989 when a slight rise was recorded. Although the total 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.

Figure 1. Total energy and energy intensity

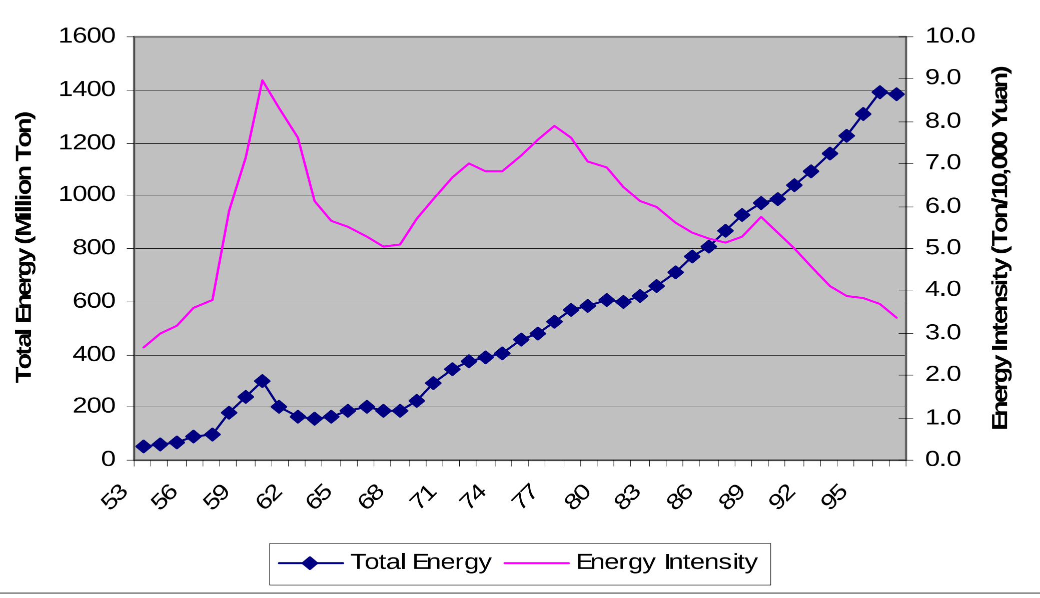
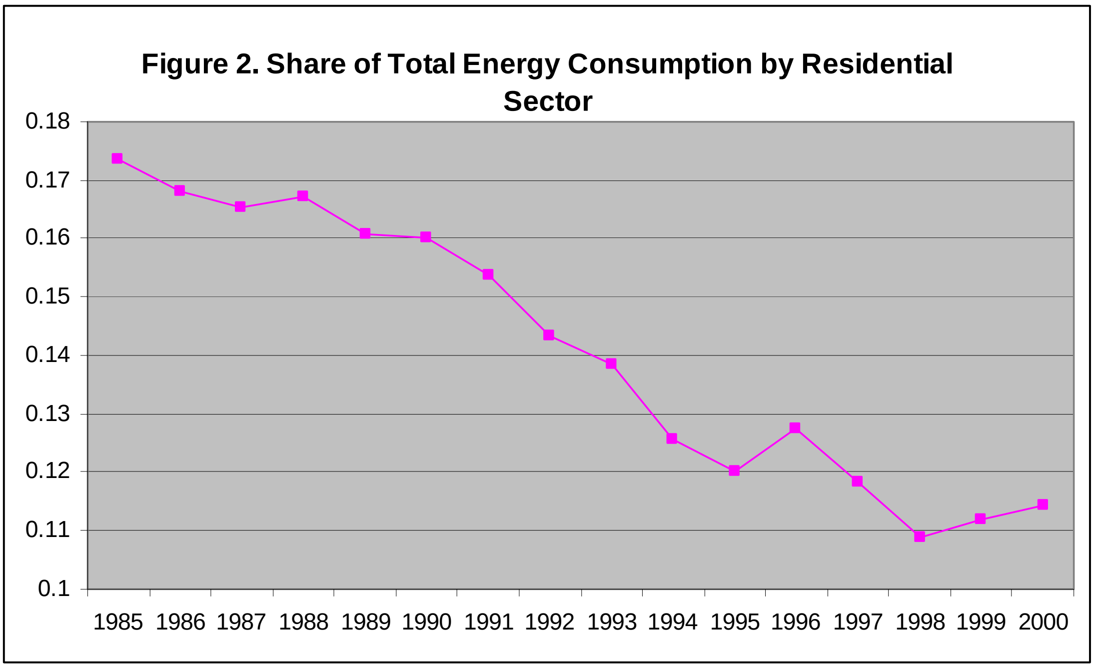


Figure 2 shows that the share of total energy consumption by the residential sector has been declining over the 15 years to 2000. Since the residential sector is the major component in final demand, the figure implies that much of the energy consumption takes place in the intermediate production.



While various studies have been carried out to explain factors driving China's energy consumption, only a few studies have focused on modelling the causes of China's decline in energy intensity. The study of Fisher-Vanden et al (2004) used the regression approach to modelling energy intensity based on sample data collected on a large number of industrial enterprises. With two most recent input-output tables at the time, Garbaccio et al (1999) employed the input-output approach to constructing an index on energy intensity. Fisher-Vanden et al found that production structure changes were one of the major factors causing the decline in energy intensity, whereas the study of Garbaccio et al pointed to technological changes being responsible for the decline in energy intensity. A direct comparison between the two studies can be difficult as production structural changes were not explicitly considered in the study of Garbaccio et al. However, the technological changes considered in the latter study were measured using the Leontief inverse which is a function of direct input-output coefficients reflecting the production process. Therefore, both studies have implied the importance of the production process in determining energy intensity for the whole economy. Nevertheless, they both have ignored that the underlying factors for the production process to impact on overall energy intensity are energy intensities of various productive industries. Since more than 90 per cent of total energy consumption takes place in the intermediate production in China, it is particularly important to study how industry energy intensities in the intermediate production and the interactions of them dictate the energy intensity for the whole economy.

In the input-output framework, technological advances in energy conservation that result in a decline in energy intensity in production firms will be recorded as a fall in input-output coefficients in the row for the energy sector. Such a fall/rise indicates that energy intensities of various industries in the production process have declined/increased. The present study focuses on the impact of such changes on overall energy intensity. In particular, the Elasticity Coefficient Analysis method due to Schnabl (2003) is adopted to devise a new method to decompose changes in overall energy intensity. It is shown that changes in overall energy intensity is comprised of changes in the technology that governs the linkage between energy intensities in the production process and final consumption, changes in the magnitude of energy intensities in the production process, and changes in final consumption composition. This method is then applied to the 1987 and 1997 Chinese input-output tables to quantify the impact of energy intensities of 13 productive sectors on the overall energy intensity. Of particular interesting is the finding that although for two sectors there had been an increasing in the magnitude of energy intensity in the production process during the 10-year period, they contributed to the reduction in the overall energy intensity thanks to changes in the technology linking energy intensities in the production process and final consumption. This result is consistent with the findings in Fisher-Vanden et al. The plan of the paper is as follows. The following section describes the decomposition method in the input-output framework. Section 3 discusses empirical results with some concluding remarks in the last section.

2. Analytical framework

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

$$\underset{n\times 1}{Y} = \underset{n\times n}{C}\,\underset{n\times 1}{Y} + \underset{n\times k}{F}\,\underset{k\times 1}{\mathrm{i}} \tag{1}$$

where the element in the ith row in Y, y_i, represents the total output of industry i; the element in the ith row and jth column in C, c_{ij}, represents the amount of y_j required to produce a unit of y_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. Of the n industries, suppose there are m industries/fuels belonging to the energy sector. One can swap rows in (1) so that the input-output matrix can be partitioned as follows,

$$\underset{n\times 1}{Y} = \begin{pmatrix} \underset{m\times 1}{Y_E} \\ \underset{(n-m)\times 1}{Y_{NE}} \end{pmatrix} = \begin{pmatrix} \underset{m\times n}{C_E} \\ \underset{(n-m)\times n}{C_{NE}} \end{pmatrix} \underset{n\times 1}{Y} + \underset{n\times k}{F}\,\mathrm{i} \tag{2}$$

where E and NE denote the energy and non-energy sectors.

Since the focus of the current paper is on energy intensity, the m fuels are aggregated to form a single energy industry and the exports and imports of the fuels were, respectively, removed from and added to Y to get the total domestic energy consumption, Q_E. That is,

$$\underset{(n-m+1)\times 1}{Q} = \begin{pmatrix} \underset{1\times 1}{Q_E} \\ \underset{(n-m)\times 1}{Y_{NE}} \end{pmatrix} = A \underset{(n-m+1)\times 1}{Q} + \underset{(n-m+1)\times k}{F}\,\mathrm{i} \tag{3}$$

where A was $\begin{pmatrix} \underset{1\times(n-m+1)}{A_E} \\ \underset{(n-m)\times(n-m+1)}{A_{NE}} \end{pmatrix}$, calculated using Q instead of Y.

In equation (3), the A_E characterises the production technology governing intermediate energy requirements for both the energy and non-energy sectors. Since A_E shows energy requirements per unit of industry output, the elements in it are actually industry energy intensities in the intermediate production (EIIP).

The total energy consumption, Q_E, is comprised of energy consumption in the intermediate production process, $A_E * Q$, and in final consumption, F_E, which consists of energy consumption in the household sector H_E, in capital formation K_E plus the difference between imports and exports of energy, $IMP_E - EXP_E$.

$$Q_E = A_E Q + F_E \text{ i}$$

or

$$Q_E = B_E F \text{ i} \qquad (4).$$

Where B_E is the row in $(I - A)^{-1} = \left[I - \begin{pmatrix} A_E \\ A_{NE} \end{pmatrix} \right]^{-1}$ corresponding to the energy sector. Equation (4) shows that B_E measures energy requirement per unit of final demand for every industry; the elements in it are, therefore, energy intensities in final consumption (EIFC). Dividing the two sides of equation (4) by total output gives overall energy intensity,

$$E_{\text{int}} = Q_E /(\text{i}'Q) = B_E S_F \text{i} \qquad (5)$$

where S_F contains the shares of final demand components in total output.

The relationship between the elements in A_E and those in B_E can be modelled using the Elasticity Coefficient Analysis (ECA) approach as discussed in Schnabl (2003). With ECA, a p per cent change in an element in A_E, a_{El} say, will result in an $G_{b_{Ej},a_{El}}$ per cent change in the element, b_{Ej} in B_E, whereby the $G_{b_{Ej},a_{El}}$ is given by the formula below,

$$G_{b_{Ej},a_{El}}(p) = \frac{b_{EE} a_{El} b_{lj}}{b_{Ej}(1 - p a_{El} b_{lE})} \qquad (6).$$

Because the $G_{b_{Ej},a_{El}}(p)$ describes the dynamic potential of changes in EIIP for sector l, it characterises the technology that governs the strength of linkages between EIIP and EIFC in the sector. Equation (6) then shows that for a given technology linking EIIP and EIFC, the EIFC at time period 1, b^1_{Ej}, can be determined by the EIFC at time period 0, b^0_{Ej}, via $b^0_{Ej} * G_{b_{Ej},a_{El}}(p)$ once the change in a^1_{El} is known. This makes it possible to evaluate the impact of changes in EIIP on EIFC and hence on overall energy intensity on a sectoral basis.

Thus, the change in energy intensity from period 0 to period 1 can be expressed as follows,

$$\begin{aligned} E^1_{\text{int}} - E^0_{\text{int}} &= B^1_E S^1_F \,\text{i} - B^0_E S^0_F \,\text{i} \\ &= (B^1_E - B^{1,0}_E) S^1_F \,\text{i} + (B^{1,0}_E - B^0_E) S^0_F \,\text{i} + B^{1,0}_E (S^1_F \,\text{i} - S^0_F \,\text{i}) \end{aligned} \qquad (7).$$

where the elements in $B^{1,0}_E$ measure EIFC in period 1 assuming that the elasticity $G_{b_{Ej}, a_{El}}(p)$ at period 0 persisted in period 1. According to Schnabl, the most influential element of the $a_{E\bullet}$s on b_{Ej} is a_{Ej}, thus the $G_{b_{Ej}, a_{El}}(p)$ is calculated at $k = l$ for the present study . Equation (7) shows that changes in overall energy intensity can be broken up into three sources of change: 1. the elasticity of EIFC with respect to EIIC $B^1_E - B^{1,0}_E$; 2. EIIP $B^{1,0}_E - B^0_E$; and 3. share of final demand in total output $S^1_F \,\text{i} - S^0_F \,\text{i}$.

Equation (7) presents the industry aggregates of the changes, which can be disaggregated so that changes in energy intensity for a particular industry can be found as shown below,

$$E^1_{\text{int},i} - E^0_{\text{int},i} = (b^1_{Ei} - b^{1,0}_{Ei}) \sum_j s^1_{ijF} + (b^{1,0}_{Ei} - b^0_{Ei}) \sum_j s^0_{ijF} + b^{1,0}_{Ei} \sum_j (s^1_{ijF} - s^0_{ijF}) \qquad (8)$$

In the section that follows, equation (8) is applied to both the 1987 and 1997 input-output tables from China.

3. Empirical results

The original 1987 and 1997 input-output tables consist of 117 industries, which have been aggregated into 13 sectors for the purposes of the present study. Table 1 contains sectoral energy shares and energy intensity in intermediate production. The second and third columns in the table show that the sectoral standing in relative energy consumption over the period 1987-1997 has hardly changed with *Energy*, *Chemical*, *Metal* and *Building Materials* remaining the top 4 energy consumers. Most of the thirteen sectors had recorded a decline in EIIP, with the most significant drop found in the Chemical, Metal and Transportation, Post and Telecommunications sectors. The four sectors that recorded a rise in EIIP were *Energy*, *Agriculture*, *Mining* and *Foodstuff*.

Table 1.
Sectoral energy shares and energy intensity in intermediate consumption (unit: 1997 Yuan)

Sector	Share of total intermediate energy consumption		A_E^{1987}	A_E^{1997}
	1987	1997		
Energy	0.29	0.30	0.2846	0.2865
Agriculture	0.04	0.04	0.0158	0.0170
Mining	0.02	0.03	0.0791	0.0841
Foodstuff	0.01	0.02	0.0123	0.0142
Textile	0.01	0.01	0.0189	0.0152
Chemical	0.12	0.12	0.1358	0.0791
Building Materials and Non-metal Mineral	0.09	0.09	0.2327	0.1193
Metal	0.12	0.10	0.1110	0.0886
Machinery and Equipment	0.06	0.05	0.0393	0.0191
Other Manufacturing	0.02	0.04	0.0553	0.0454
Transportation, Post and Telecommunications	0.09	0.06	0.8200	0.1149
Other Services	0.08	0.09	0.1073	0.0294
Construction	0.04	0.06	0.0997	0.0357

The overall energy intensities in monetary terms for 1987 and 1997 were 0.09603 and 0.05779, respectively, calculated using equation (5) with the 1987 data in 1997 prices. The decline is 0.03824 whose breakdown by industry and sources of change is presented in Table 2.

The last row in Table 2 presents the aggregates of the sectoral figures to obtain the change in overall energy intensity and the sources of change for the whole economy. It shows that while all of the three sources contributed to the decline in the overall energy intensity, 0.03788 out of the total reduction of 0.03824, or 99% came from changes in EIIP. The first column in the table shows the contributions to overall energy intensity by industry computed with equation (8). Of the thirteen sectors, ten recorded a contribution to the decline in overall energy intensity with the energy, mining and building materials sectors moving in the opposite direction. The second column lists the contribution to the overall energy intensity of the elasticity of EIFC with respect to EIIC. For most of the sectors, changes in the elasticity had helped reduction of overall energy intensity. The more significant reductions were observed in *Machinery and Equipment*, *Other Services* and *Construction*. Mixed evidence was found in column 3 which presents how changes in EIIC affected overall energy intensity. Six of the thirteen sectors had contributed to the rise in the overall energy intensity whereas the opposite was true for the other seven. *Construction* and *Other Services* recorded the most significant contribution to the decline in the overall energy intensity. The last column gives the effects of changes in the shares of final demand on overall energy intensity. Similar to column 3, the results are mixed with six sectors contributing an increase in the overall energy intensity.

Table 2.
Changes in overall energy intensity by industry and by source

Sector	Changes in overall energy intensity	Changes in overall energy intensity due to changes in		
		$B_E^1 - B_E^{1,0}$	$B_E^{1,0} - B_E^0$	$S_F^1 \text{ i} - S_F^0 \text{ i}$
Energy	0.00212	-0.00002	0.00005	0.00209
Agriculture	-0.00351	-0.00002	0.00079	-0.00428
Mining	0.00027	0.00000	0.00001	0.000265
Foodstuff	-0.00203	-0.00001	-0.00103	-0.00099
Textile	-0.00226	0.00000	0.00039	-0.00264
Chemical	-0.00264	-0.00002	-0.00132	-0.00129
Building Materials	0.00152	-0.00001	0.00013	0.00139
Metal	-0.00325	0.00000	0.00041	-0.00366
Machinery and Equipment	-0.00812	-0.00003	-0.00262	-0.00546
Other Manufacturing	-0.00048	0.00000	-0.00019	-0.00029
Transportation, Post and Telecommunications	-0.00231	-0.00001	-0.00240	0.00010
Other Services	-0.00420	-0.00005	-0.00943	0.005278
Construction	-0.01337	-0.00003	-0.02267	0.009341
Total	**-0.03824**	**-0.00021**	**-0.03788**	**-0.00015**

4. Concluding remarks

In the input-output framework, a falling/rising direct input-output coefficient in the row for the energy sector reflects a falling/rising EIIP in the corresponding industry. This paper has focused on decomposing the impact of such changes in EIIP on overall energy intensity. With the aid of the Elasticity Coefficient Analysis, changes in overall energy intensity were decomposed into two sources, namely, changes in EIFC and changes in final demand composition. Changes in EIFC were further decomposed into changes in technology characterised by the elasticity of EIFC with respect to EIIC and changes in EIIP. The overall energy intensity had declined from 0.09603 in 1987 to 0.05779 in 1997, measured as the ratio of total expenditure on energy to total output in 1997 prices. Thirteen sectors have been included in the study with four of them witnessing a rising EIIP over the 10-year period. It was found that at the economy level changes in EIIC were the predominant source for the decline in the overall energy intensity. At the sectoral level, changes in the elasticity of EIFC with respect to EIIP did not cause the sectors to increase the overall energy intensity. Such changes helped most of the sectors contribute a decrease in the overall energy intensity. The other two sources had mixed impact on sectoral contributions to the level of overall energy intensity. The major contribution of the paper is the anatomy of technological changes, which enabled the finding that energy use in the intermediate production was the key factor in driving overall energy intensity in China between 1987-1997.

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