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The fluctuations of China's energy intensity: Biased technical change

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HIGHLIGHTS

- Biased technical change is considered in the adjusting the input–output tables.
- The level of biased technical change is determined by TFP and energy efficiency.
- The increase in energy intensity was mostly attributed to the structural change.
- The changes in the production technology actually decreased the energy intensity.
- The decomposition results are sensitive to the level of biased technical change.

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ABSTRACT

The fluctuations of China's energy intensity have attracted the attention of many scholars, but fewer studies consider the data quality of official input–output tables. This paper conducts a decomposition model by using the Divisia method based on the input–output tables. Because of the problems with input–output tables and price deflators, we first produce constant prices to deflate the input–output tables. And then we consider different levels of biased technical change for different sectors in the adjusting the input–output table. Finally, we use RAS technique to adjust input–output matrix. Then the decomposition model is employed to empirically analyze the change of China's energy intensity. We compare the decomposition results with and without biased technical change and do sensitive analysis on the level of biased technical change. The decomposition results are that during 2002–2007, the energy intensity of coal and electricity increased, the changes were mostly attributed to the structural change and the contribution was 594.08%, 73.88%, respectively; as for crude oil and refined oil, the energy intensity decreased, the changes were mostly attributed to the changes in the production technology and the contribution was 978.89%, 246.95%, respectively. And the results of sensitive analysis shows that 1% variation of the level of biased technical change will cause at most 0.6% change of decomposition results. Therefore, we can draw our conclusions: compared to the decomposition without biased technical change, decomposition results are sensitive to the level of biased technical change; the level of biased technical change can be determined by the difference in the change rate of total factor productivity and energy efficiency.

1. Introduction

The fluctuations of China's energy intensity have attracted the attention of many scholars. Most of the studies focus on the national trend of energy intensity, energy consumption, etc. For example, Wei and Liao [1] examined the impact of economic structure on the energy macro-efficiency, and applied Divisia and input–output analysis to analyze the way the industrial structure, final use structure and national income distribution structure affected China's energy macro-efficiency. Liu and Jiang [2] employed the structural decomposition method to study the increasing trend of China's energy consumption in recent years. There are similar studies like energy intensity changes (Wang and He [3]), emerging energy expenditure relationship (Kahrl and Roland-Holst [4]), biomass and China's carbon emissions (Ma and Stern [5]), China's energy intensity (Zhao et al. [6]).

Some other studies consider the changes in energy intensity or energy consumption at a specific sector. Cao et al. [7] used a structural decomposition method to reveal the changes in the total

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embodied energy requirement for the agricultural sector. Li et al. [8] applied life cycle assessment to estimate total energy use, the criteria emissions and the greenhouse gases emissions of a traction motor production and disposal. There are similar studies such as residential carbon emission (Fan et al. [9]), residential energy consumption (Zhao et al. [10]).

Besides the national studies and sectoral studies, the rest pay attention to the changes in energy intensity at regional level. Li and Leung [11] applied a panel cointegration and error-correction model to investigate the relationship between coal consumption and real GDP of 23 provinces in China. Liao et al. [12] used the structural decomposition analysis method to analyze the changes in energy intensity in Beijing. There are similar studies like regional CO_2 emissions in Beijing (Wang et al. [13]), multi-region energy consumption in China (Ma [14]).

This paper decomposes the changes in China's energy intensity between 2002 and 2007 using a Divisia decomposition method and input–output tables. Compared to most of the other similar researches, the main improvement is that this paper considers the biased technical change between different years which draws on the work of Garbaccio et al. [15]. Garbaccio et al. [15] found that material-biased technical change, deverticalization and errors in the data contributed to an overstatement of gross output data in China. Because of these data problems, we should consider biased technical change in decomposition. Therefore we come up with an adjustment framework of input–output tables to obtain a consistent data set. Different from Garbaccio et al. [15], we use input–output tables with more detailed sectors to get more accurate results. Furthermore, we present a definition of the biased technical change and apply different levels of biased technical change for different sectors instead of a fixed level in Garbaccio et al. [15].

Section 2 describes the structure of energy intensity decomposition model. Section 3 discusses the problems of corresponding data and the framework of adjustment. Section 4 presents the decomposition results for changes in China's energy intensity during the period of 2002–2007; the last section concludes and discusses future research.

2. Decomposition model for energy intensity

Divisia method (As far as we know, Boyd et al. [16] introduced the Divisia index method to the decomposition in energy) and two related methods (which include arithmetic form [17] and logarithmic form [18,19]) used in discrete state have been widely used in the studies of social, energy, resources, environment, pollution, etc. The two approximate methods both have residual and meet the properties of monotonicity, commensurability, expansibility, linear homogeneity and transitivity [20].

Our Divisia model is based on the work of Garbaccio et al. [15] and also uses the input–output tables. Input–output analysis is widely used in the social, energy and environmental aspects, such as energy use and air pollutants emissions (Cellura et al. [21]), socio-economic impacts of sugarcane-derived bioethanol production (Herreras et al. [22]), greenhouse gas (Cansino et al. [23], Limmeechokchai and Suksuntornsiri [24]), energy and GHG emission intensity (Chung et al. [25]), Socio-technological impact (Chung et al. [26]).

In the general input–output model, the sum of intermediate use and final use equal the gross output and using the matrix pattern, i.e.

$$AX + Y = X \tag{1}$$

where A is the input–output matrix, X is the vector of gross output and Y is the vector of final use.

According to the input–output table and expenditure approach of GDP, the final use can be divided in:

$$Y = CON + GOV + INV + STO + EX - IM \tag{2}$$

where CON, GOV, INV, STO, EX, IM is the vector of household consumption expenditure, government consumption expenditure, gross fixed capital formation, change in inventories, exports and imports, respectively.

We rewrite the final use and its components as follows:

$$\begin{aligned} Y = \gamma Q &= CON + GOV + INV + STO + EX - IM \\ &= (\gamma^{con} + \gamma^{gov} + \gamma^{inv} + \gamma^{sto} + \gamma^{ex} - \gamma^{im})Q \end{aligned} \tag{3}$$

where Q is the sum of final use (i.e. GDP); and γ^{con}, γ^{gov}, γ^{inv}, γ^{sto}, γ^{ex}, γ^{im} is the share vector of household consumption expenditure, government consumption expenditure, gross fixed capital formation, changes in inventories, exports and imports, respectively.

We rewrite the final use in Eq. (3) as the sum of domestic production and imports minus imports:

$$Y = Y^d - IM = (\gamma^d - \gamma^{im})Q \tag{4}$$

In general, Eq. (1) has the following solution:

$$X = (I - A)^{-1}Y = LY = L\gamma Q \tag{5}$$

And the domestic energy use (EU) in a country equals domestic production plus imports minus exports:

$$EU = e(X + IM - EX) = e(L\gamma Q + IM - EX) \tag{6}$$

where e is a vector with n sectors. The elements, which correspond to the energy sectors, are ones, and the rest are zeros. The purpose of this vector is to select the energy sector.

According to the definition of the energy intensity, we get the energy intensity (EI) by energy type as:

$$\begin{aligned} EI &= \frac{EU}{Q} = \frac{e(L\gamma Q + IM - EX)}{Q} = eL\gamma + e\gamma^{im} - e\gamma^{ex} \\ &= eL\gamma^d - eL\gamma^u + e\gamma^{im} - e\gamma^{ex} \end{aligned} \tag{7}$$

Differentiating Eq. (7) with respect to time and we get:

$$\dot{EI}_{it} = \sum_j e_i \dot{L}_{ijt}\gamma_{jt} + \sum_j e_i L_{ijt}\dot{\gamma}^d_{jt} - \sum_j e_i L_{ijt}\dot{\gamma}^{im}_{jt} + e_i\dot{\gamma}^{im}_{jt} - e_i\dot{\gamma}^{ex}_{jt} \tag{8}$$

where i, j is the ith and jth sector, t stands for the time.

Then both sides of Eq. (8) are divided by EI_{it}:

$$\begin{aligned} \frac{\dot{EI}_{it}}{EI_{it}} &= \sum_j \frac{e_i L_{ijt}\gamma_{jt}}{EI_{it}} \times \frac{\dot{L}_{ijt}}{L_{ijt}} + \sum_j \frac{e_i L_{ijt}\gamma^d_{jt}}{EI_{it}} \times \frac{\dot{\gamma}^d_{jt}}{\gamma^d_{jt}} - \sum_j \frac{e_i L_{ijt}\gamma^{im}_{jt}}{EI_{it}} \times \frac{\dot{\gamma}^{im}_{jt}}{\gamma^{im}_{jt}} \\ &\quad + \sum_j \frac{e_i\gamma^{im}_{jt}}{EI_{it}} \times \frac{\dot{\gamma}^{im}_{jt}}{\gamma^{im}_{jt}} - \sum_j \frac{e_i\gamma^{ex}_{jt}}{EI_{it}} \times \frac{\dot{\gamma}^{ex}_{jt}}{\gamma^{ex}_{jt}} \end{aligned} \tag{9}$$

And then curvilinear integrating the both sides of Eq. (9), we get:

$$\begin{aligned} \int_\Gamma \frac{\dot{EI}_{it}}{EI_{it}} &= \int_\Gamma \sum_j \frac{e_i L_{ijt}\gamma_{jt}}{EI_{it}} \times \frac{\dot{L}_{ijt}}{L_{ijt}} + \int_\Gamma \sum_j \frac{e_i L_{ijt}\gamma^d_{jt}}{EI_{it}} \times \frac{\dot{\gamma}^d_{jt}}{\gamma^d_{jt}} \\ &\quad - \int_\Gamma \sum_j \frac{e_i L_{ijt}\gamma^{im}_{jt}}{EI_{it}} \times \frac{\dot{\gamma}^{im}_{jt}}{\gamma^{im}_{jt}} + \int_\Gamma \sum_j \frac{e_i\gamma^{im}_{jt}}{EI_{it}} \times \frac{\dot{\gamma}^{im}_{jt}}{\gamma^{im}_{jt}} \\ &\quad - \int_\Gamma \sum_j \frac{e_i\gamma^{ex}_{jt}}{EI_{it}} \times \frac{\dot{\gamma}^{ex}_{jt}}{\gamma^{ex}_{jt}} \end{aligned} \tag{10}$$

where Γ is the integration path, which stands for curve segments ($eL\gamma^d$, $eL\gamma^{im}$, $e\gamma^{im}$ and $e\gamma^{ex}$) in the time interval $(0,T)$. According to the Hulten [27], when the curve is linearly homogeneous, the curve integral is path independent. Referring to the definition of energy