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Structural decomposition analysis on energy intensity changes at regional level*

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Abstract: As China's energy intensity fluctuated in recent years, it is necessary to examine whether this fluctuations happened at a regional level. This paper conducts a decomposition model by using the structural decomposition analysis (SDA) method at a regional level. Then this model is employed to empirically analyze the changes of Beijing's energy intensity. The conclusions are as follows: during 2002—2010, except petroleum, the energy intensity decreased and the changes were mostly attributed to the technology changes, while the final use variation actually increased the energy intensity; comparing different periods of 2002—2010, the decline rates of energy intensity for coal and hydropower were decreasing, resulting from the production technology being more energy-intensive than before; The energy intensity changes of petroleum firstly increased substantially then decreased moderately.

Keywords: structural decomposition analysis; input-output analysis; energy intensity

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With the industrialization between 1980 and 2001, the energy intensity (i.e., energy consumption per unit of GDP) appeared to be in a gradually declining trend, from 0.340 tons of coal equivalent (Tce) per thousand Yuan to 0.116 Tce per thousand of Yuan. Here electricity is converted to Tce by average quantity of fuel used for power generation at constant prices of year 2002. However, since 2002, China's energy intensity has appeared to fluctuate abnormally.

The fluctuations of China's energy intensity have attracted the attention of domestic and international scholars, because they did not follow the pattern of developed countries. Cao *et al* [1] used a structural decomposition method based on input-output analysis, to reveal to what degree the changes in total embodied energy requirement for the agricultural sector were due to changes in energy-use technology and the inner-relationship between two agricultural sectors, i.e., farming and animal husbandry. And they concluded that since 1978, China’s agro-ecosystem has increased its productivity, but due to the overuse of fossil energy inputs (particularly fertilizers and pesticides), the energy-use efficiency of agro-ecosystem had decreased in farming. Behjat and Steven [2] focused on decomposing U.S. household energy consumption changes into several factors that had affected its growth. Wei and Liao *et al* [3] 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. Raymond and Guy [4] applied a panel cointegration and error-correction model to investigate the relationship between coal consumption and real GDP of 23 provinces in China during the period of 1985—2008. Liu and Jiang [5] employed the structural decomposition method to study the increasing trend of China's energy consumption in recent years, and found that structural effect corresponding to mediate inputs and demand effect resulting from investment and export demand were the driving forces for rapid growth in the energy consumption. Wang and He [6] used Divisia method to analyze China’s energy intensity changes in the period of 1994—2005, and concluded that the technology improvement was the main reason for energy intensity decline, but after 2001 the contribution of technology improvement started to decrease; Meanwhile, the industrial structural change promoted the energy intensity decline before 1998 and later increased the energy intensity. Fredrich and David [7] examined the emerging energy expenditure relationship in China during the period of 1997—2002, 2002—2004 and 1997— 2004, and they found that among others, export was the growing contributor to growth in the energy consumption. Furthermore, they concluded that simply changing the final use could not necessarily change the energy and resource intensity of the Chinese economy.

Besides the national-level researches, there were some regional studies. Wang and Tian [8] used the Laspeyres index method to decompose the changes in energy intensity of Heibei province during the period of 2005-2009, and found that rather than structural effect, the technical effect played a bigger role on the reduction of energy intensity. Yu [9] studied the regional imbalance and spatial correlations of energy intensities among China’s provinces by using spatial panel data model, and he found that GDP per capital, transportation infrastructure, the level of marketization and scientific and technological input significantly reduced the energy intensity. Song and Zheng [10] employed decomposition analysis and econometric analysis to investigate the driving forces behind China’s changing energy intensity by using a provincial-level panel data set for the period of 1995—2009. Wu [11] examined the changes and determinants of the energy intensity in China’s regional economies and found that the main contributing factors affecting energy intensity were the improvement in energy efficiency and changes in the economic structure.

In general, most of the studies tended to analyze the energy intensity changes at a national level. Though few scholars studied at the regional level, this paper argues that the regional level is necessary for the following reasons: first, different results might be reflected at national and regional levels, e.g., China's energy intensity appeared to fluctuate after 2002, but Beijing's energy intensity showed a continued downward trend; second, the national level researches reflected an average level, while the regional level ones can focus on the regions themselves, as well as the differences among different regions, such as energy consumption structure and economic structure; third, compared with the national-level data, there will be data reflecting the relations between different regions at the regional levels, such as the regional input-output tables including imports and exports data from both domestic regions and foreign countries. Therefore, this paper will analyze the energy intensity changes at the regional level and select Beijing as an example to conduct the empirical analysis. For other regions, the analysis is similar.

This paper conducts a structural decomposition analysis (SDA) method to examine whether the energy intensity of Beijing decreased in recent years and the causes of its changes. Section 1 describes the structure of energy intensity decomposition model. Section 2 discusses the corresponding data sources and data processing. Section 3 presents the results for model application and the decomposition of changes in Beijing's energy intensity during the period of 2002—2010; the last section offers the conclusions and future work.

1 SDA model for decomposing changes in energy intensity

SDA has been widespread used in the studies related to energy, resources, environment, pollution, etc. For instance, Maurizio *et al* [12] investigated the energy use and air emissions related to household final use of Italy during the period of 1999—2006 and identified the sources of variations in energy and environmental indicators. Asuka and Glen [13] quantified the economic factors driving greenhouse gas emissions in Norway.

Our SDA model is based on the work of Lin [14] and Lin and Polenske [15]. Similar to Lin and Polenske [15], we analyze the energy intensity changes by energy types. However, we use the average of two different SDA forms, instead of by only using a fixed one, and we focus on the energy intensity changes at the regional level rather than on a national level.

As it is known in the input-output model, the sum of intermediate use and final use equal the gross output in each sector, i.e.,:

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

where $\boldsymbol{A}$ is the input-output matrix; $\boldsymbol{X}$ is the vector of gross output; and $\boldsymbol{Y}$ is the vector of final use.

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

$$\boldsymbol{X}=\left(\boldsymbol{I}-\boldsymbol{A}\right)^{-1}\boldsymbol{Y} \tag{2}$$

where $\boldsymbol{I}$ is the identity matrix; and $\left(\boldsymbol{I}-\boldsymbol{A}\right)^{-1}$ is the matrix of total input requirements.

According to the components of final use in the input-output table, the final use can be divided in 8 parts, i.e.:

$$\boldsymbol{Y}=\boldsymbol{C}+\boldsymbol{V}+\boldsymbol{W}+\boldsymbol{G}+\boldsymbol{E}-\boldsymbol{U}+\boldsymbol{M}-\boldsymbol{N} \tag{3}$$

where $\boldsymbol{C}$ is the vector of household consumption expenditure; $\boldsymbol{V}$ is the vector of gross fixed capital formation; $\boldsymbol{W}$ is the vector of changes in inventories; $\boldsymbol{G}$ is the vector of government consumption expenditure; $\boldsymbol{E}$ is the vector of exports; $\boldsymbol{U}$ is the vector of imports; $\boldsymbol{M}$ is the vector of sending-outs, which stands for exports to other regions in the same country; and $\boldsymbol{N}$ is the vector of moving-ins, which stands for imports from other regions in the same country.

We can rewrite the final use and its components as follows:

$$\begin{aligned} \boldsymbol{Y} &= \gamma\boldsymbol{Q} = \boldsymbol{C} + \boldsymbol{V} + \boldsymbol{W} + \boldsymbol{G} + \boldsymbol{E} - \boldsymbol{U} + \boldsymbol{M} - \boldsymbol{N} \\ &= \left(\gamma^c + \gamma^v + \gamma^w + \gamma^g + \gamma^e - \gamma^u + \gamma^m - \gamma^n\right)\boldsymbol{Q} \end{aligned} \tag{4}$$

where $\boldsymbol{Q}$ is vector of total demand; and γ^c, γ^v, γ^w, γ^g, γ^e, γ^u, γ^m, γ^n is the share vector of household consumption expenditure, gross fixed capital formation, changes in inventories, government consumption expenditure, exports, imports, sending-outs and moving-ins, respectively.

As for the calculation of energy consumption, Lin and Polenske [15] applied a "hybrid" method and replaced all the energy rows in the monetary input-output table with physical energy flows. Instead, we use "energy prices", which are not actual prices in market but physical production per gross output of different kinds of energy, to convert the monetary values in the energy rows to physical quantities. By using "energy prices", the total energy consumption can be written as:

$$\begin{aligned} \boldsymbol{E}_{\text{tot}} &= \boldsymbol{eX} \\ &= \boldsymbol{eAX} + \boldsymbol{eY} \\ &= \boldsymbol{E}_{\text{int}} + \boldsymbol{E}_{\text{fnl}} \end{aligned} \tag{5}$$

where $\boldsymbol{E}_{\text{tot}}$ is the vector of total energy consumption in the region; $\boldsymbol{E}_{\text{int}}$ is the vector of energy consumption used as intermediate input; and $\boldsymbol{E}_{\text{fnl}}$ is the vector of energy consumption used by final users; $\boldsymbol{e}$ is a diagonal matrix. The elements, which correspond to the energy sectors, are the "energy prices" (unit: 0.1 million Tce per thousand Yuan) for each type of energy, and the rest elements are zeros. The purpose of this matrix is to select the energy rows from the input-output tables and convert them into physical unit.

By combining and adjusting Eqs. (2) and (5), we can write the vector of energy consumption for intermediate use as:

$$\begin{aligned} \boldsymbol{E}_{\text{int}} &= \boldsymbol{eAX} = \boldsymbol{e}\left[\left(\boldsymbol{I} - \boldsymbol{A}\right)^{-1} - \boldsymbol{I}\right]\boldsymbol{Y} \\ &= \boldsymbol{e}\left[\left(\boldsymbol{I} - \boldsymbol{A}\right)^{-1} - \boldsymbol{I}\right]\gamma\boldsymbol{Q} = \boldsymbol{eF}\gamma\boldsymbol{Q} \end{aligned} \tag{6}$$

where $\boldsymbol{F} = \left(\boldsymbol{I} - \boldsymbol{A}\right)^{-1} - \boldsymbol{I}$. When we calculate the energy consumption in the region for a certain year, we should exclude energy used for exports and imports, sending-outs and moving-ins and changes in inventories from the energy used in final use. Mathematically, we have

$$\begin{aligned} \boldsymbol{E}_{\text{fnl}} &= \boldsymbol{E}_{\boldsymbol{y}} + \boldsymbol{E}_{\boldsymbol{u}} - \boldsymbol{E}_{\boldsymbol{e}} - \boldsymbol{E}_{\boldsymbol{w}} + \boldsymbol{E}_{\boldsymbol{n}} - \boldsymbol{E}_{\boldsymbol{m}} \\ &= \boldsymbol{e}\left(\boldsymbol{Y} + \boldsymbol{U} - \boldsymbol{E} - \boldsymbol{W} + \boldsymbol{N} - \boldsymbol{M}\right) \\ &= \boldsymbol{e}\left(\boldsymbol{C} + \boldsymbol{G} + \boldsymbol{V}\right) = \boldsymbol{e}\left(\gamma^c + \gamma^g + \gamma^v\right)\boldsymbol{Q} \end{aligned} \tag{7}$$

where $\boldsymbol{E}_y$, $\boldsymbol{E}_u$, $\boldsymbol{E}_e$, $\boldsymbol{E}_w$, $\boldsymbol{E}_n$, $\boldsymbol{E}_m$ are energies used for final use, imports, exports, sending-outs and moving-ins, respectively.

In summary, the total energy consumption $\boldsymbol{E}_{\text{tot}}$ in the region can be written as:

$$\boldsymbol{E}_{\text{tot}} = \boldsymbol{eF\gamma Q} + \boldsymbol{e}\left(\boldsymbol{\gamma}^c + \boldsymbol{\gamma}^g + \boldsymbol{\gamma}^v\right)\boldsymbol{Q} \tag{8}$$

Therefore, the energy intensity in the economy is defined as the total energy consumption $\boldsymbol{E}_{\text{tot}}$ divided by the total demand $\boldsymbol{Q}$, i.e.,

$$\text{EI} = \frac{\boldsymbol{E}_{\text{tot}}}{\boldsymbol{Q}} = \boldsymbol{eF\gamma} + \boldsymbol{e}\left(\boldsymbol{\gamma}^c + \boldsymbol{\gamma}^g + \boldsymbol{\gamma}^v\right) \tag{9}$$

Eq.(9) shows that the energy intensity in the region is determined by the energy price matrix $\boldsymbol{e}$ and total input requirement $\boldsymbol{F}$, which are mainly caused by changes in production technology and the structure of final use. As for the changes in energy intensity,

$$\begin{aligned} \Delta\text{EI}_{0\text{-}T} &= \text{EI}_T - \text{EI}_0 \\ &= \boldsymbol{e}_T\boldsymbol{F}_T\boldsymbol{\gamma}_T - \boldsymbol{e}_0\boldsymbol{F}_0\boldsymbol{\gamma}_0 \\ &\quad + \boldsymbol{e}_T\left(\boldsymbol{\gamma}_T^c + \boldsymbol{\gamma}_T^g + \boldsymbol{\gamma}_T^v\right) - \boldsymbol{e}_0\left(\boldsymbol{\gamma}_0^c + \boldsymbol{\gamma}_0^g + \boldsymbol{\gamma}_0^v\right) \end{aligned} \tag{10}$$

where operator $\Delta_{0\text{-}T}$ indicates changes in the period of 0—T.

Similar to Lin and Polenske [15], we decompose the energy intensity changes into final use variation and technical changes，so we also introduce hypothetical economies as follows:

$$\text{EI}_{F_T\gamma_0} = \boldsymbol{e}_T\boldsymbol{F}_T\boldsymbol{\gamma}_0 + \boldsymbol{e}_0\left(\boldsymbol{\gamma}_0^c + \boldsymbol{\gamma}_0^g + \boldsymbol{\gamma}_0^v\right) \tag{11}$$

$$\text{EI}_{F_0\gamma_T} = \boldsymbol{e}_0\boldsymbol{F}_0\boldsymbol{\gamma}_T + \boldsymbol{e}_T\left(\boldsymbol{\gamma}_T^c + \boldsymbol{\gamma}_T^g + \boldsymbol{\gamma}_T^v\right) \tag{12}$$

By using $\text{EI}_{F_T\gamma_0}$ and $\text{EI}_{F_0\gamma_T}$ as the reference points respectively, we can rewrite the energy intensity changes from time 0 to T , i.e.,:

$$\begin{aligned} \Delta\text{EI}_{0\text{-}T} &= \text{EI}_T - \text{EI}_{F_T\gamma_0} + \text{EI}_{F_T\gamma_0} - \text{EI}_0 \\ &= \Delta\left(\boldsymbol{eF}\right)_{0\text{-}T}\boldsymbol{\gamma}_0 + \boldsymbol{e}_T\boldsymbol{F}_T\Delta\boldsymbol{\gamma}_{0\text{-}T} + \\ &\quad \Delta\left(\boldsymbol{e\gamma}^c\right)_{0\text{-}T} + \Delta\left(\boldsymbol{e\gamma}^g\right)_{0\text{-}T} + \Delta\left(\boldsymbol{e\gamma}^v\right)_{0\text{-}T} \end{aligned} \tag{13}$$

$$\begin{aligned} \Delta\text{EI}_{0\text{-}T} &= \text{EI}_T - \text{EI}_{F_0\gamma_T} + \text{EI}_{F_0\gamma_T} - \text{EI}_0 \\ &= \Delta\left(\boldsymbol{eF}\right)_{0\text{-}T}\boldsymbol{\gamma}_T + \boldsymbol{e}_0\boldsymbol{F}_0\Delta\boldsymbol{\gamma}_{0\text{-}T} + \\ &\quad \Delta\left(\boldsymbol{e\gamma}^c\right)_{0\text{-}T} + \Delta\left(\boldsymbol{e\gamma}^g\right)_{0\text{-}T} + \Delta\left(\boldsymbol{e\gamma}^v\right)_{0\text{-}T} \end{aligned} \tag{14}$$

In this paper, we choose the average of these two forms, i.e.,

$$
\begin{aligned}
\Delta \mathrm{EI}_{0\text{-}T} &= \Delta\left(\boldsymbol{eF}\right)_{0\text{-}T}\boldsymbol{\alpha} + \boldsymbol{\beta}\Delta\boldsymbol{\gamma}_{0\text{-}T} + \\
&\quad \Delta\left(\boldsymbol{e}\boldsymbol{\gamma}^{c}\right)_{0\text{-}T} + \Delta\left(\boldsymbol{e}\boldsymbol{\gamma}^{g}\right)_{0\text{-}T} + \Delta\left(\boldsymbol{e}\boldsymbol{\gamma}^{v}\right)_{0\text{-}T} \\
&= \Delta\left(\boldsymbol{eF}\right)_{0\text{-}T}\boldsymbol{\alpha} + \left[\boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{c}_{0\text{-}T} + \Delta\left(\boldsymbol{e}\boldsymbol{\gamma}^{c}\right)_{0\text{-}T}\right] \\
&\quad + \left[\boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{g}_{0\text{-}T} + \Delta\left(\boldsymbol{e}\boldsymbol{\gamma}^{g}\right)_{0\text{-}T}\right] \\
&\quad + \left[\boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{v}_{0\text{-}T} + \Delta\left(\boldsymbol{e}\boldsymbol{\gamma}^{v}\right)_{0\text{-}T}\right] \\
&\quad + \boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{w}_{0\text{-}T} + \boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{e}_{0\text{-}T} \\
&\quad + \left(-\boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{u}_{0\text{-}T}\right) + \boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{m}_{0\text{-}T} + \left(-\boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{n}_{0\text{-}T}\right)
\end{aligned}
\tag{15}
$$

where $\boldsymbol{\alpha} = \frac{1}{2}\left(\boldsymbol{\gamma}_T + \boldsymbol{\gamma}_0\right)$ and $\boldsymbol{\beta} = \frac{1}{2}\left(\boldsymbol{e}_0\boldsymbol{F}_0 + \boldsymbol{e}_T\boldsymbol{F}_T\right)$.

And from Eq.(16), we can decompose the energy intensity change into production technology changes ($\Delta\left(\boldsymbol{eF}\right)_{0\text{-}T}\boldsymbol{\alpha}$) and final use variation, which include structure changes of household consumption ($\boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{c}_{0\text{-}T} + \Delta\left(\boldsymbol{e}\boldsymbol{\gamma}^{c}\right)_{0\text{-}T}$), government consumption ($\boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{g}_{0\text{-}T} + \Delta\left(\boldsymbol{e}\boldsymbol{\gamma}^{g}\right)_{0\text{-}T}$), investment ($\boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{v}_{0\text{-}T} + \Delta\left(\boldsymbol{e}\boldsymbol{\gamma}^{v}\right)_{0\text{-}T}$), inventory change ($\boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{w}_{0\text{-}T}$), exports ($\boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{w}_{0\text{-}T}$), imports ($-\boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{u}_{0\text{-}T}$), sending-outs ($\boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{m}_{0\text{-}T}$) and moving-ins ($-\boldsymbol{\beta}\Delta\boldsymbol{\gamma}^{n}_{0\text{-}T}$).

2 Data sources and processes

We need three main categories of data for 2002, 2005, 2007, and 2010 respectively to apply the SDA model well, i.e., input-output tables, price indexes and energy related production data.

The commodity-by-commodity tables are introduced as the input-output tables for Beijing in 2002, 2005, 2007 and 2010, formed through the System of National Accounts (SNA) [16]. We classify the production sectors of Beijing's economy into 40 industrial groups, and ignore the Petroleum and Natural Gas Extraction, because there is no petroleum or gas production in Beijing and all of the crude oil and natural gas come from moving-ins.

The analysis needs different price levels unified in each year's input-output table of changes in energy intensity. Thus, the table data in 2005, 2007 and 2010 tables are adjusted to the price level in 2002. The price indexes are from the Beijing Statistics Bureau [16] and our adjustment.

Because of the limitation of energy data for 40 sectors at the region level, we use energy prices for coal, petroleum and hydropower to transform the values of energy rows from the primary input-output table into physical quantities. For different years and energy types, the prices are different, so we should select the energy production data which include coal, petroleum and hydropower for 2002, 2005, 2007 and 2010 from National Statistics Bureau of China [16] and Beijing Statistics Bureau [16].

3 Empirical analysis on changes in Beijing's energy intensity

By using Eq. (15), we can calculate to what degree the technical changes and final use variation account for the changes in Beijing's energy intensity.

As listed in Tab. 1, between 2002 and 2010, Beijing’s total energy intensity and energy intensity of coal and hydropower decreased by 18.98 Gce, 22.77 Gce and 0.271 Gce per Yuan, respectively. The technology change was the main factor that pushed energy intensity downward. With all else being equal, this change would decrease the total energy intensity, and energy intensity of coal and hydropower by 25.07 Gce, 31.94 Gce and 0.256 Gce per Yuan respectively. However, because of the increase in the government consumption expenditure, exports and sending-outs, the final use variation actually offsets the fall in the energy intensity of total energy, coal and hydropower. With other factors being unchanged, the final use variation would increase the energy intensity of total energy, coal and hydropower by 6.09 Gce, 9.17 Gce and 0.015 Gce per Yuan respectively. A major exception was petroleum, whose energy intensity increased by 4.06 Gce per Yuan. The main reason was technology changes, which accounted for 175.38% of the changes in energy intensity, and the final use variation actually decreased the energy intensity.

When conducting a further analysis, we can find that during different periods of 2002–2010, the decline rates of Beijing's energy intensity were not the same, as indicated by Fig. 1 and Tab. 1. During the periods of 2002–2005, 2005–2007 and 2007–2010, Beijing’s energy intensity of coal decreased 11.37 Gce, 7.30 Gce and 4.10 Gce per Yuan respectively, which occupied 49.93%, 32.06%, 18.01% of the energy intensity decline between 2002 and 2010. Among these results, we can find that the decline rate was decreasing, the reason for which was that the technology changes decreased while the final use variation almost stayed the same.

As for hydropower, the trend of the energy intensity was similar to that of coal. During the periods of 2002–2005, 2005–2007 and 2007–2010, Beijing’s energy intensity of hydropower decreased by 0.199 Gce, 0.044 Gce and 0.028 Gce per Yuan respectively, which occupied 73.43%, 16.24%, 10.33% of the energy intensity decline between 2002 and 2010. By comparing the data of 2002 – 2005 and 2005 – 2007, we can see that the technology changes decreased by from 1.69 Gce to 0.62 Gce per Yuan and final use variation turned to slow down the energy intensity decline. And after 2007, the technology changes decreased by from 0.62 Gce to 0.32 Gce per Yuan, which made the energy intensity fall further.

Tab. 1 SDA of primary energy intensity changes in Beijing from 2002–2010 (Gce per Yuan）

					Changes in components							
Period	Energy type	Actual change in EI	Technical change	Final use variation	Household consumption expenditure	Government consumption expenditure	Gross fixed capital	Inventory	Export	Import	Sending-out	Moving-in
2002 - 2005	Coal	-11.37	-15.06	3.69	-3.10	0.08	-1.56	-0.60	5.90	-6.33	-6.83	16.14
	Petroleum	0.15	1.55	-1.40	-0.52	-0.09	-0.48	0.00	2.34	-2.65	-3.28	3.29
	Hydropower*	-1.99	-1.69	-0.30	-0.36	-0.03	-0.05	0.03	0.40	-0.40	-0.33	0.44
	Total energy	-11.42	-13.69	2.27	-3.66	-0.02	-2.04	-0.60	8.28	-9.03	-10.14	19.47
2005 -	Coal	-7.30	-11.04	3.73	0.62	1.26	0.05	0.67	2.81	-2.13	3.83	-3.37
	Petroleum	5.68	7.26	-1.58	0.59	0.97	0.17	0.29	0.76	-1.09	4.71	-7.98

2007	Hydropower*	-0.44	-0.62	0.19	-0.01	0.08	-0.01	0.00	0.16	-0.10	0.22	-0.15
	Total energy	-1.67	-3.84	2.18	1.21	2.24	0.21	0.97	3.59	-3.23	8.56	-11.37
2007 - 2010	Coal	-4.10	-6.48	2.38	0.06	0.14	-1.29	-0.6	0.44	0.78	4.03	-1.17
	Petroleum	-1.76	0.03	-1.80	1.65	0.26	-1.82	-0.38	1.45	-3.75	1.83	-1.04
	Hydropower*	-0.28	-0.32	0.03	0.02	0.02	-0.05	0.00	-0.04	-0.02	0.22	-0.12
	Total energy	-5.89	-6.48	0.59	1.71	0.40	-3.11	-0.99	1.89	-2.97	5.88	-2.22
2002 - 2010	Coal	-22.77	-31.94	9.17	-1.05	2.65	-4.38	-0.15	6.24	-6.80	10.98	1.68
	Petroleum	4.06	7.13	-3.06	1.66	1.0	-1.76	0.07	4.55	-6.90	2.58	-4.26
	Hydropower*	-2.71	-2.56	-0.15	-0.30	0.14	-0.21	0.06	0.32	-0.46	0.80	-0.50
	Total energy	-18.98	-25.07	6.09	0.58	3.67	-6.17	-0.08	10.82	-13.75	13.64	-2.62

* Unit: 0.1 Gce per Yuan

However, the trend of energy intensity for the petroleum was different from those of coal and hydropower. During the periods of 2002–2005, 2005–2007 and 2007–2010, Beijing's energy intensity of petroleum increased by 0.15 Gce, 5.68 Gce and -1.76 Gce per Yuan respectively, which occupied 3.69%, 139.90%, -43.35% of the energy intensity growth between 2002 and 2010, respectively. By comparing the data of 2002–2005 and 2005–2007, we can see that the technology changes increased by from 1.55 Gce to 7.26 Gce per Yuan, which strengthens the energy intensity, changes substantially. And after 2007, the technology changes turned to be less energy-intensive and the final use variation decreased by from -1.58 Gce to -1.8 Gce per Yuan, which weakens the energy intensity a little.

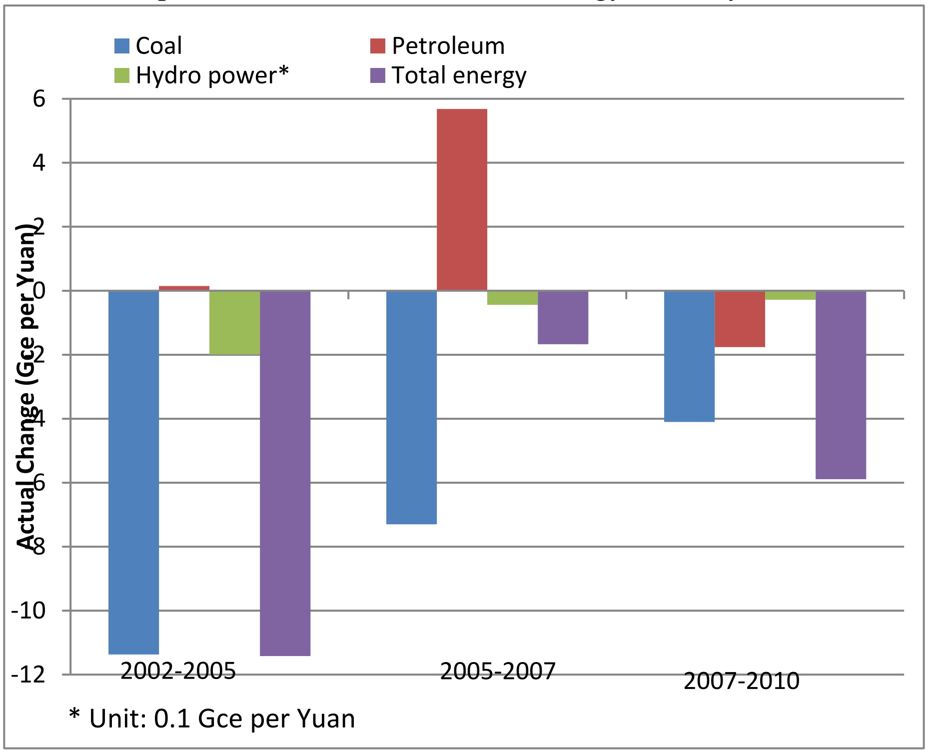

Fig.1 Energy intensity changes during different periods for different energy types

4 Conclusions

Since 1977, the fluctuations of energy intensity in China have drawn considerable interest from both domestic and international researchers. Unlike most studies, this paper examined the changes in energy intensity at regional levels by using an SDA model and then decomposed the energy intensity change of Beijing in the period of 2002–2010. Our main findings are as follows.

(1)During 2002–2010, except petroleum, the technical changes contributed to the main part of decline in the energy intensity rather than the final use variation.

(2)From the comparison of different periods of 2002–2010, the decline rates of energy intensity for coal and hydropower were decreasing, resulting from the more energy-intensive technology changes.

(3)The energy intensity changes of petroleum were different, i.e., they firstly increased substantially and then decreased modestly.

The SDA model at one regional level can be used in studies related to energy intensity changes of other regions. However, this model is a single-region model and does not consider the relations among different regions. The limitation can be overcome by introducing an inter-regional input-output model in the future study.

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