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# Revisiting drivers of energy intensity in China during 1997–2007: A structural decomposition analysis

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## HIGHLIGHTS

- We analyzed energy intensity change from production and consumption perspectives.
- We extended the research scope of energy intensity to cover household consumption.
- Sectoral energy efficiency improvement contributed most to energy intensity decline.
- Impact of production structure change on energy intensity varied at different times.
- Growing export demand newly became main driver of China's energy intensity increase.

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## ABSTRACT

The decline of China's energy intensity slowed since 2000. During 2002–2005 it actually increased, reversing the long-term trend. Therefore, it is important to identify drivers of the fluctuation of energy intensity. We use input–output structural decomposition analysis to investigate the contributions of changes in energy mix, sectoral energy efficiency, production structure, final demand structure, and final demand category composition to China's energy intensity fluctuation during 1997–2007. We include household energy consumption in the study by closing the input–output model with respect to households. Results show that sectoral energy efficiency improvements contribute the most to the energy intensity decline during 1997–2007. The increase in China's energy intensity during 2002–2007 is instead explained by changes in final demand composition and production structure. Changes in final demand composition are mainly due to increasing share of exports, while changes in production structure mainly arise from the shift of Chinese economy to more energy-intensive industries. Changes in energy mix and final demand structure contribute little to China's energy intensity fluctuation. From the consumption perspective, growing exports of energy-intensive products and increasing infrastructure demands explain the majority of energy intensity increase during 2002–2007.



## 1. Introduction

The latest International Energy Agency statistics show that China was the world's largest energy producer in 2010 with 2456 million tonnes of oil equivalent (mtoe) of total primary energy production (IEA, 2013). In addition, China has newly become the world's largest energy consumer with 1514 mtoe of total final consumption in 2010, 14 mtoe more than that the U.S. consumes (IEA, 2013). As a result, China has become the world's largest carbon dioxide ($CO_2$) emitter (Gregg et al., 2008). More than 85% of China's $CO_2$ emissions originate from fossil fuel combustion (Guan et al., 2012). To date, a number of studies have been conducted to analyze the historical trajectory of China's $CO_2$ emissions and its implications for achieving China's $CO_2$ mitigation targets (Minx et al., 2011; Steckel et al., 2011; Wang and Liang, 2013; Zha et al., 2010; Zhang et al., 2009; Zhang, 2009).

Currently, improving energy intensity is one of the most important actions to reduce China's $CO_2$ emissions as existing policy instruments in China predominantly focus on the upstream energy supply and consumption side instead of the downstream emission side. For example, Chinese government has mandated to reduce energy intensity (i.e., energy consumption per unit gross domestic product (GDP) measured by constant price, similarly hereinafter) by 20% during 2006–2010 as one of the constraint targets in its 11th Five Year Plan (FYP). The recent 12th FYP

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(2011–2015) continues to mandate a 16% reduction of energy intensity.

China has experienced a dramatic decline in energy intensity from the onset of economic reform in the late 1970s until 2002. However, the energy intensity increased strikingly during 2003–2005 and declined slightly in 2006 (Liao et al., 2007; Wu, 2012). Analyzing driving forces of this energy intensity fluctuation can provide foundations for identifying the emphasis of China's energy and climate policy-making, which have been investigated by a number of decomposition studies (Huang, 1993; Lin and Polenske, 1995; Sinton and Levine, 1994; Sun, 1998; Zhang, 2003; Zhao et al., 2010). Technological change is regarded as the dominant contributor to China's energy intensity decline, while there is disagreement on the role of production structure change. Most of previous studies applied the index decompositions analysis (IDA) model to decompose the energy intensity changes from production perspective. Although it is flexible in formulation and has a relatively lower data requirement, the IDA method covers only the direct effect, ignoring the effects of the indirect energy demand and final demand (also named from consumption perspective). Meanwhile, IDA studies are normally for a sector of energy consumption, such as industry or transportation instead of the whole economy (Su and Ang, 2012b).

Several structural decomposition analysis (SDA) approaches have also been conducted to investigate China's energy intensity changes. The SDA model is based on input–output tables (IOTs) and could distinguish between a range of technological and structural effects that are impossible in the IDA model (Ma and Stern, 2008). In particular, SDA model can shape socio-economic drivers from both production and final demand perspectives.

Garbaccio et al. (1999) studied China's energy intensity decline during 1987–1992, disaggregating the economy into 29 sectors. Their main conclusion was that technical change within sectors accounted for most of the decline in energy intensity while structural change actually increased energy intensity. Chai et al. (2009) decomposed China's energy intensity change during 1992–2004 into error factors, technology change, and final demand structure change according to the 30-sector hybrid energy IOTs. They pointed out that China's energy intensity was also sensitive to final demand structure change during 1992–1997. Fan and Xia (2012) used a SDA based on 44-sector physical-monetary mixed energy IOTs to explore driving forces of China's energy intensity changes during 1987–2007. Five decomposed factors in their study were energy input coefficient, technology coefficient, final demand structure by product, final demand by category, and final energy consumption coefficient. They found out that industry structure and technology improvements have major influences on energy intensity changes. The two-polar decomposition method was used in their study, which is not an ideal decomposition (Su and Ang, 2012b). Furthermore, in existing SDA studies, sectors are highly aggregated to reveal sectoral detail of economic structure. This disadvantage limits effective policy decisions at sectoral or product scale.

With these limitations in mind, in order to provide an in-depth understanding of the driving forces of China's energy intensity fluctuation during 1997–2007, we carry out an ideal SDA applying the full D&L method proposed by Dietzenbacher and Los (1998). By closing basic monetary input–output tables with respect to households, changes of aggregate energy intensity (i.e., covers both production and household energy consumption) are investigated within the input–output analysis framework, which is a non-traditional approach compared to previous SDA studies. The share of household energy consumption in China's total energy consumption is around 10–11% (NBS, 2001, 2004, 2008a), which should not be neglected. Finally, we discuss the implications of our findings for China's energy and climate policies.

## 2. Methodology and data

### 2.1. Environmental input–output analysis (EIOA)

Energy consumption of the production sectors in a given period of time can be determined by the standard economic input–output model as follows (Miller and Blair, 2009):

$$e_t = rX = r(I-A)^{-1}y = rLy \qquad (1)$$

where $e_t$ is energy consumption for all production sectors, $r$ is a row vector representing each production sector's energy efficiency (i.e., measured by energy usage per unit total output), $X$ is a vector of total output from each sector, $I$ is the identity matrix, $A$ is the direct requirements matrix, $L=(I-A)^{-1}$ is the *Leontief Inverse Matrix* (Miller and Blair, 2009), and $y$ is a column vector representing each sector's final demand (i.e., household consumption, government consumption, capital investment, stock change, and export).

China's 1997, 2002 and 2007 monetary input–output tables (MIOTs) are used (NBS, 1999, 2006, 2009) in this study. Different years have slightly different industry classifications—124 sectors for 1997, 122 sectors for 2002, and 135 sectors for 2007. The data are converted into a consistent industry classification with 101 economic sectors and then converted into 2002 constant prices using the GDP deflators from the world economic outlook database (IMF, 2012). Given the purpose of this study, we do not use sectoral price deflators for constant price conversion, although it represents an interesting avenue for future research. The Chinese MIOTs follow standard formats except for a final demand column called "others" which can be interpreted as errors representing different data sources (Liang et al., 2013a, 2013c, 2012, 2013d, Minx et al., 2011; Peters et al., 2007). We do not include this column in our calculation of total outputs. Thus, total output of each sector is given as the sum of the intermediate flows and the final demand excluding "others."

In order to analyze the changes and driving forces of aggregate energy intensity of an economy within the input–output analysis framework, which is induced by both production and household energy consumption, we close the basic input–output model for household. This is known as the partially closed input–output model with endogenous consumption and has been studied by many researchers (Cloutier and Thomassin, 1994; Miller and Blair, 2009; Miyazawa, 1976; Miyazawa and Masegi, 1963; Wakabayashi and Hewings, 2007). The household sector is treated endogenously and assumed to behave like other industrial sectors with a linear and homogeneous consumption function (Batey et al., 1987; Miller and Blair, 2009).

It requires a column and a row for the new household sector. In the present paper, the household consumption (i.e., final consumption of urban and rural households), which is part of the final demand, is closed into the intermediate delivery matrix to represent the inputs of household sector (purchases of consumption commodities). Laborers′ remuneration, which is part of the value added, fills in the row value of household sector to show how its output (labor services) is used as an input by the other sectors. Strictly speaking, the row value of household sector should be the household income, which is not the same as laborers′ remuneration. However, laborers′ remuneration in input–output tables covers most of the household income in China. For example, the share of income from wages and salaries together with household operations in laborers′ remuneration is around 85.3% in 2007 in China (Chen et al., 2010). This assumption in our study leaves out other income sources such as properties income and transfer income. Detail of the partially closed input–output model is given in Appendix A. Thus, the modified MIOTs have 102 sectors for each. Aggregate energy consumption and energy intensity of