



Driving factors behind carbon dioxide emissions in China: A modified production-theoretical decomposition analysis



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ABSTRACT

Research on the driving factors behind carbon dioxide emission changes in China can inform better carbon emission reduction policies and help develop a low-carbon economy. As one of important methods, production-theoretical decomposition analysis (PDA) has been widely used to understand these driving factors. To avoid the infeasibility issue in solving the linear programming, this study proposed a modified PDA approach to decompose carbon dioxide emission changes into seven drivers. Using 2005–2010 data, the study found that economic development was the largest factor of increasing carbon dioxide emissions. The second factor was energy structure (reflecting potential carbon), and the third factor was low energy efficiency. Technological advances, energy intensity reductions, and carbon dioxide emission efficiency improvements were the negative driving factors reducing carbon dioxide emission growth rates. Carbon dioxide emissions and driving factors varied significantly across east, central and west China.

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1. Introduction

China is the world's largest developing country and second-largest economy, and has grown rapidly as a result of reform and increased openness. This growth has come with high levels of fossil energy consumption, and high carbon dioxide emissions. In 1978, China's carbon dioxide emissions generated by fossil fuel consumption were less than 15 hundred million tons. By 2007, emissions had risen to approximately 60.7 hundred million tons (International Energy Agency (IEA), 2009). China has now surpassed the United States (U.S.) as the largest worldwide carbon emitter. Furthermore, China's promotion of industrialization and urbanization further propels future energy consumption and carbon dioxide emissions. As noted by IEA (2009), China's aggregate carbon dioxide emissions may reach 116 hundred million tons by 2030, and account for nearly 48.6% of global emissions. The fast growth and increasing carbon dioxide emissions pose great challenges as the world works to reduce global greenhouse gas emissions.

The Chinese government is working to transform itself into a low-carbon and sustainably developing country through a series of policy

measures that will fulfill its international responsibilities to reduce greenhouse gas emissions and alleviate resulting environmental impacts. In 2006, China's central government announced a target of a 20% reduction in energy consumption per unit of gross domestic product (GDP) during its 11th Five-Year Plan period. In the same year, the *National Assessment Report on Climate Change* was passed with new climate change policies.

In 2007, the Chinese government published *China's National Climate Change Program*, identifying key areas for greenhouse gas emissions reduction. On the eve of the 2009 *Copenhagen Climate Conference*, China announced a quantitative carbon dioxide emission reduction target, proposing that carbon dioxide emissions per unit of GDP be reduced by 40–45% between 2005 and 2020. In 2011, the 12th Five-Year Plan (2011–2015) set a binding target that China's energy consumption should be reduced by 16%, and that carbon dioxide emissions per unit of GDP should be reduced by 17%. In the meantime, the goal is to increase the proportion of non-fossil fuels in primary energy consumption by 11.4% (up from 8.3% in 2010). These actions demonstrate China's commitment to address climate change over the next five years.

To achieve these goals, targeted policies and measures towards carbon dioxide emission reduction are needed. Answers to many questions are needed to make these policies more scientific and effective. For example, what factors drive the sustained rise of China's carbon dioxide

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emissions? To what extent do different drivers influence carbon dioxide emissions? Are drivers consistent among different regions?

Index decomposition analysis (IDA) and structural decomposition analysis (SDA) are the two main methods for analyzing the driving factors behind carbon dioxide emissions (Ang and Choi, 1997; Hetherington, 1996; Lise, 2006; Yabe, 2004). Generally, IDA decomposes aggregate carbon dioxide emissions and carbon dioxide intensity into economic effects, structural effects, population effects, and others (Ang and Choi, 1997; Ang and Zhang, 2000; Xu and Ang, 2013). The SDA approach is based on an input–output model analyzing the direct or indirect effects that production sectors have on carbon dioxide emissions (Chang and Lin, 1998; Su and Ang, 2012; Wang et al., 2013; Zhang, 2009).

In addition to IDA and SDA approaches, Zhou and Ang (2008) proposed a new decomposition analysis, based on production-theoretical decomposition analysis (PDA). PDA combines distance functions and data envelopment analysis (DEA) to decompose aggregate carbon dioxide emission changes into seven factors (Zhang et al., 2012; Zhou and Ang, 2008). Compared with IDA and SDA approaches, the PDA approach has advantages in terms of its theoretical basis, data requirements, decomposition forms, and computing methods. Particularly, the PDA approach segregates technological factors affecting carbon dioxide emissions into two components: energy-saving technology and emission-reducing technology (Zhang and Da, 2013; Zhang et al., 2013; Zhou and Ang, 2008).

Based on the work of Zhou and Ang (2008), several researchers proposed expanded PDA approaches. The researchers included Li (2010), Kim and Kim (2012), Zhang et al. (2012, 2013) and Lin and Du (2014). However, all these PDA approaches may face the challenge of the infeasibility of DEA linear programming. This study tries to modify the PDA approach, and then apply it to analyze the driving factors of carbon dioxide emissions in China.

This paper is organized as follows. Section 2 reviews the related literature. Section 3 presents the modified PDA approach and compares it with the traditional approach. Section 4 constructs an empirical study using variables from China, and Section 5 summarizes the main findings of the study and outlines possible policy implications for China.

2. Literature review

With greenhouse gas issues receiving increasing worldwide attention, assessing the driving factors behind carbon dioxide emissions is theoretically, scientifically, and practically important, with numerous related studies (Ang and Choi, 1997; Hetherington, 1996; Kim and Kim, 2012; Yabe, 2004; Zhang et al., 2013; Zhou and Ang, 2008). There are generally two approaches for decomposing carbon dioxide emission changes: IDA and SDA.

Generally, IDA decomposes aggregate carbon dioxide emission changes into several components. This method specifically includes the Divisia, Laspeyres, Paasche, Fisher, and Marshall–Edgeworth index approaches and their transformations (Ang and Choi, 1997; Ang and Liu, 2007; Ang and Zhang, 2000). Among these, the Divisia and Laspeyres index approaches are more widely applied (Ang, 2004, 2005; Sun, 1999; Wood and Lenzen, 2006). After introducing the IDA application and methodology, Ang (2004) advocated the logarithmic mean Divisia index (LMDI) for general use because of its theoretical foundation, adaptability, ease of use, and interpretation of results in the context of IDA. Recently, Xu and Ang (2013) provided a complete literature review of the evolution of the IDA approach, and its applications to the carbon emissions field.

Compared to IDA, SDA approach is based on the input–output model to analyze the direct or indirect effects that production categories have on carbon dioxide emissions. Conclusions based on SDA are more complete, but the approach requires more data. Particularly, IDA adopts both additive and multiplicative forms, while SDA mainly uses the additive form (Su and Ang, 2012). Recently, there were some methodological improvements in multiplicative SDA. For example, Su and Ang (2014) introduced the attribution analysis into the multiplicative SDA to give the contributions of the individual components at the finer

level. Besides, Su and Ang (2015) further introduced four different models to calculate a country's aggregate carbon intensity changes using multiplicative SDA.

Early empirical research based on IDA and SDA primarily targeted carbon-intensive industries, such as transportation (Kwon, 2005; Scholl et al., 1996). Papagiannaki and Diakoulaki (2009) used LMDI to consider six factors in comparing carbon dioxide changes and trends emitted by Denmark and Greece passenger cars. Andreoni and Galmarini (2012) also analyzed European transportation. González and Martínez (2012) discussed the influence of six factors (including structure, energy intensity, and end-use fuel mix) on industrial sector emissions in Mexico, based on a Laspeyres index approach. Sheinbaum-Pardo et al. (2012) used the arithmetic mean Divisia index (AMDII) approach to analyze energy consumption and carbon emissions changes in Mexico's manufacturing sector from 1990 to 2008.

Yabe (2004), Hetherington (1996), Chang and Lin (1998), and Alcántara and Padilla (2003) used different forms of IDA or SDA approaches to analyze carbon dioxide emissions changes for industries in Japan, England, Taiwan, and Spain. Other scholars have focused on sectors outside industry and transportation. For example, Wier (1998) used the SDA approach to analyze carbon emissions changes in Denmark's household sector; Suh (2006), Butnar and Llop (2011) discussed the factors driving carbon dioxide emissions in U.S. and Spain service industries.

Decomposing carbon emissions into specific categories or factors can support emission reduction policies for specific industries, but fail to address macro-level carbon dioxide changes. Therefore, scholars are increasingly studying the driving factors of carbon dioxide emissions at the country level. Davis et al. (2003) found that energy consumption structure and energy efficiency changes were primary contributors to carbon emissions changes in the U.S., while Lise (2006) concluded that economic development was the main driver of Turkey's carbon emissions increase. Additionally, Hatzigeorgiou et al. (2008) applied two variations of Divisia indexes at a state level to decompose Greece's carbon dioxide emissions into four factors. The study found that income effect was the most important factor in increasing carbon emissions.

PDA was first proposed by Zhou and Ang (2008). Expanding this basic method, Li (2010) constructed a PDA approach to assess contributions of seven factors to carbon dioxide emissions, using the Shephard input distance function. Zhang et al. (2012) expanded the recognized carbon dioxide drivers from seven to nine factors, and applied this PDA to empirically analyze 20 developed countries with data from 1995 to 2005. Additionally, Kim and Kim (2012) combined PDA and LMDI, presenting a decomposition approach with six factors contributing to carbon emissions, and applied it to 43 industries.

Because China is a leading carbon dioxide emitter, there is much literature on the country's carbon dioxide drivers, at national, industrial, regional, and city levels (Fan et al., 2007; Wang et al., 2005; Zhang, 2009; Zhou et al., 2014). Earlier literature focused on analysis of changes in carbon dioxide emissions across 12 Asian nation utility industries, including China (Shrestha and Timilsina, 1997). More recently, Ma and Stern (2008) used the LMDI approach to investigate carbon emission reductions in China from 1971 to 2003. Zhang et al. (2009) studied the factors behind carbon emission changes across agriculture, transportation, and other China industries from 1991 to 2006. Using the SDA approach, Zhang (2009) assessed several factors contributing to the micro carbon intensity decline in China from 1992 to 2006. In addition, using LMDI and SDA approaches, Zhao et al. (2010) and Wang et al. (2013) discussed the major drivers of carbon dioxide emission changes in Shanghai industry from 1996 to 2007, and in Beijing from 1997 to 2010. Zha et al. (2010) compared the factors impacting carbon dioxide between China's urban and rural residents.

Since the PDA approach was proposed, selected researchers have applied it to conduct decomposition analyses of China's carbon dioxide emissions. For example, Li (2010) and Zhang and Da (2013) both

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