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Multiplicative structural decomposition and attribution analysis of carbon emission intensity in China, 2002–2012

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ABSTRACT

Energy/emission intensity indicators measure the relationship between economic development and climate change. These intensity indicators are preferentially used in assessment criteria for mitigation goals in places such as China. This paper investigates the driving factors of changes in the national CO_2 emission intensity and their contributions to reductions at the sector level in China from 2002 to 2012 using multiplicative structural decomposition analysis (SDA) and attribution analysis. Both Leontief and Ghosh input-output models are used in the study. The empirical results indicate: 1) the energy intensity effect is the main driver that decreases the aggregate emission intensity from both the demand and supply sides; 2) structural effects, such as the energy structure effect and domestic Ghosh structure effect, promote the increase in aggregate emission intensity principally; and 3) to a large extent, sector “smelting and pressing of metals”, “manufacture of non-metallic mineral products” and “chemical industry” are the top three sectors that contribute to the negative energy intensity effect. Ultimately, several discussions and conclusions associated with the empirical results, result stability and research extensibility are presented.

1. Introduction

The excessive carbon emissions brought on by energy consumption-driven economic growth have attracted great attention around the world. Most previous studies have shown that economic activity was the major driver for the increase in CO_2 emissions (Li et al., 2017; Su et al., 2017; Shen et al., 2018). In this regard, improvement of the intensity indicator, which is defined as the ratio of CO_2 emissions to economic activity, should be interpreted as a rebalance between environmental protection and economic development. In recent years, the emission intensity indicator, namely, the CO_2 emissions per unit of Gross Domestic Product (GDP), has been studied frequently, especially for the developing countries such as China (Xia et al., 2015; Su and Ang, 2015, 2016; Dong et al., 2018; Wang et al., 2018). In addition, the intensity indicator is preferred when a government plans to establish a mitigation goal, such as the intended nationally determined contributions of China, India, Mexico and Singapore (Su and Ang, 2015; Wang et al., 2017a). Thus far, the intensity indicator has been popularly acknowledged and utilized within academic and practical fields.

To achieve the rebalance, China endeavors to adjust the economic development pattern and has made its commitments using the intensity indicator. China has promised to reduce its CO_2 emission intensity by 40–45% by 2020 on the basis of the 2005 level. In addition, China further promised to reduce carbon emission intensity by 60–65% by 2030 on the basis of the 2005 level (NDRC, 2015). Naturally, the influencing factors of CO_2 emission intensity are numerous, such as the emission coefficient, energy utilization, production structure, and so on. From the practical perspective, it is of significance to identify the key factors in terms of the influences and their degree of impact in order to achieve the 2020/2030 goals. From the academic perspective, it is fundamental to choose and build the appropriate methods to describe and study the above issue.

Index decomposition analysis (IDA) and structural decomposition analysis (SDA) are two popular and widely used methods that are used to quantitatively study the influencing factors of an

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aggregate indicator. Within environmental research, IDA is based on energy/emissions at the sector level, whereas SDA is focused on the economy-wide changes in energy/emissions based on the input-output (I-O) technique (Su and Ang, 2012a, 2012b). Taking advantage of time series data, IDA can detect direct influences, such as the overall activity level, energy/emission intensity, energy structure and emission coefficients (Chen and Yang, 2015; Liobikienė et al., 2016; Cruz and Dias, 2016). Nevertheless, with the help of input-output tables, SDA can identify both direct and indirect drivers, such as the Leontief structure effect, inputs substitution and final demand structure (Duarte et al., 2013; Li and Wei, 2015; Kim et al., 2015). Detailed comparisons between IDA and SDA can be found in Hoekstra and van den Bergh (2003) and Su and Ang (2012a). In this study, SDA under an input-output model framework is preferred, aiming at CO_2 emission intensity at the national level.

There are two decomposition forms within SDA, namely, additive and multiplicative decompositions. Additive decomposition is expressed as the sum of the decomposed effects, which is usually implemented to the absolute indicator, such as energy consumption and CO_2 emissions (Cellura et al., 2012; Su and Ang, 2012a). Multiplicative decomposition is expressed as the product of the decomposed effects, which is usually implemented with intensity and elasticity indicators, such as energy consumption intensity (Fan and Xia, 2012; Zhang and Lahr, 2014a) and CO_2 emission intensity (Xia et al., 2015; Su and Ang, 2015). In terms of SDA research, the applications of additive decomposition are abundant (Liang et al., 2016; Wei et al., 2017; Wang and Yang, 2016). However, the multiplicative decomposition is seldom adopted due to the complexity associated with model development and the difficulty in interpreting results at the sector level (Su and Ang, 2012a, 2014a). In consideration of CO_2 emission intensity, this paper adopts multiplicative SDA and the related attribution analysis to investigate influencing factors and sectoral contributions.

The foundation of SDA is input-output (I-O) models, which can be divided into the Leontief model and the Ghosh model. Within environmental research, the Leontief I-O model is always adopted for consumption-based analysis (Su et al., 2010; Su and Ang, 2012a). On the other hand, the Ghosh I-O model is built from the supply perspective and is applied to income-based analysis (Su and Ang, 2015; Liang et al., 2016). In light of the differences between the Leontief and Ghosh I-O models (Yan et al., 2016), the analyses and results associated with CO_2 emission intensity are different. In consideration of research completeness, it has been suggested that the Leontief I-O model and Ghosh I-O model, which is regarded as a beneficial supplement, should be adopted simultaneously (Wu and Chen, 1990; Su and Ang, 2015). In SDA studies, researchers have adopted additive SDA based on the Leontief and Ghosh I-O models (Zhang, 2010; Liang et al., 2016) and have obtained rich and comprehensive results. It could be expected that multiplicative SDA based on the Leontief and Ghosh I-O models would also work well, but needs more attention (Su and Ang, 2015; Wang et al., 2017b). Within the economy-energy-environment system of China, multiplicative SDA based on the Leontief and Ghosh I-O models could allow us to identify the influencing factors of CO_2 emission intensity from both the demand and supply perspectives simultaneously.

This paper is the first and the most detailed research using multiplicative SDA and attribution analysis based on different I-O models to study CO_2 emission intensity in China. The main contributions are: 1) Both the Leontief and Ghosh I-O models are used to carry out the analysis from both the demand and supply sides, respectively. Accordingly, we expect to obtain rich and comprehensive results which could show the necessity and superiority of simultaneously adopting the Leontief and Ghosh I-O models. 2) The combination of multiplicative SDA and attribution analysis allows us to obtain the decomposition results not only at the aggregate level but also at the sector level, consistently and in a multiplicative way. 3) To reduce the potential impacts caused by sector and temporal aggregation, all official published and latest Chinese I-O tables (including benchmark and extended I-O tables) are adopted during the research period. With the most detailed database, the chaining analysis is carried out under an SDA framework. It is worth noting that Chinese energy consumption grew at half of the rate of GDP growth during the 1980s and 1990s. This trend reversed immediately after 2001 (Zhang and Lahr, 2014a). In terms of rapid growth in energy consumption and the latest data availability, the research period of this paper is from 2002 to 2012.

The remaining sections are organized as follows. Section 2 explores the development of the method and the research gap through reviewing studies of SDA and attribution analysis, especially those done in a multiplicative way. Section 3 describes the detailed formulation of the model and empirical database. The empirical results for the multiplicative SDA of aggregate CO_2 emission intensity and the attribution analysis of energy intensity effects are summarized in Section 4. Section 5 discusses the results and future research. Section 6 concludes the study.

2. Literature review

There are three popular decomposition methods implemented in SDA, namely, the traditional *ad hoc*, D&L and Logarithmic Mean Divisia Index (LMDI) methods (Su and Ang, 2012a). The traditional *ad hoc* decomposition method has always been applied to decomposition analysis when the number of driving forces is relatively large or within the two-stage decomposition (Chang et al., 2008; Lim et al., 2009; Kim et al., 2015). D&L and its approximate method are commonly applied in the field of energy/CO_2 emissions, embodied at national (Liang et al., 2016), regional (Wei et al., 2017) and industrial (Lin and Xie, 2016) levels. LMDI, proposed by Ang and Choi (1997), was the first ideal decomposition in IDA and exact decomposition in SDA. LMDI was first applied in SDA by Wachsmann et al. (2009) and the related guide for implementation is provided in Ang (2015). In recent years, LMDI has been gradually applied in the SDA model for direct and indirect energy/CO_2 emissions at both the national and regional levels (Dong et al., 2010; Wang et al., 2015; Deng et al., 2016; Wang and Yang, 2016). Additionally, more detailed SDA studies from before 2010 have been reviewed and summarized by Su and Ang (2012a).

Within the environmental field, the additive SDA scheme is the unique choice with regard to application studies before 2010. At that time, another decomposition scheme, or multiplicative SDA, was only applied in economic research, such as labor productivity growth (Dietzenbacher et al., 2000), labor costs (De Boer, 2009) and consumption per worker (Dietzenbacher et al., 2007) but was not involved in the energy and emissions fields (Su and Ang, 2012a; Wang et al., 2017b). Fortunately, multiplicative SDA based on the Leontief I-O model has been gradually applied in the economic-environmental system in recent years. Fan and Xia (2012) studied changes in China's energy intensity and investigated five driving forces behind its changes from 1987 to 2007. Zhang and Lahr (2014a) decomposed the change in national energy consumption and energy intensity into five driving forces and performed a detailed analysis from the view of China's economic structure, technology, urbanization and lifestyle. Zhang and Lahr (2014b) described the regional disparities of energy consumption in China. In their study, the effects of production structure and final demand were further decomposed into 3 and 2 sub-effects, respectively. From the global perspective, Zhong (2015) launched