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Changes in carbon intensity in China's industrial sector: Decomposition and attribution analysis

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HIGHLIGHTS

- The study analyzed the changes in carbon intensity in China's industrial sector.
- An extension of the Divisia index decomposition methodology was utilized.
- Energy efficiency improvement was the dominant factor reducing carbon intensity.
- The sub-sector contributions to the energy efficiency improvement varied markedly.
- Emission coefficient growth can be mainly due to the expansion of electricity.

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ABSTRACT

The industrial sector accounts for 70% of the total energy-related CO_2 emissions in China. To gain a better understanding of the changes in carbon intensity in China's industrial sector, this study first utilized logarithmic mean Divisia index (LMDI) decomposition analysis to disentangle the carbon intensity into three influencing factors, including the emission coefficient effect, the energy intensity effect, and the structure effect. Then, the analysis was furthered to explore the contributions of individual industrial sub-sectors to each factor by using an extension of the decomposition method proposed in Choi and Ang (2012). The results indicate that from 1996 to 2012, the energy intensity effect was the dominant factor in reducing carbon intensity, of which *chemicals, iron and steel, metal and machinery,* and *cement and ceramics* were the most representative sub-sectors. The structure effect did not show a strong impact on carbon intensity. The emission coefficient effect gradually increased the carbon intensity, mainly due to the expansion of electricity consumption, particularly in the *metal and machinery* and *chemicals* sub-sectors. The findings suggest that differentiated policies and measures should be considered for various industrial sub-sectors to maximize the energy efficiency potential. Moreover, readjusting the industrial structure and promoting clean and renewable energy is also urgently required to further reduce carbon intensity in China's industrial sector.

1. Introduction

China is currently the world's largest emitter of CO_2 emissions (IEA, 2012). Approximately 70% (average share from 1996 to 2012) of China's total energy-related CO_2 emissions derived from the industrial sector. Undoubtedly, emission mitigation in China's industrial sector is critical for the low-carbon transition, not only for China, but also for the rest of the world. However, regional goals for economic growth and large costs make it difficult to slow the overall scale of China's industrial development in the short term (Wu and Huo, 2014). Thus, efficiency improvements have become more important to counteracting the expansion of industrial emissions by reducing carbon intensity. Carbon intensity is the ratio of CO_2 emissions to gross domestic product (GDP), which is commonly used to represent a country's energy and environmental performance (Su and Ang, 2015). In 2009, the Chinese government committed that by 2020, the carbon intensity of its GDP would be reduced by 40–45% compared with 2005 levels (Kang et al., 2014).

To reduce carbon intensity, the State Council, National Development and Reform Commission (NDRC) and other responsible

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ministries or administrations of China have announced and implemented a large series of policies and measures targeting the industrial sector over the past few decades. These policies can be mainly classified into three groups of government interventions, including energy efficiency improvement, structure optimization, and energy mix upgrade. To improve energy efficiency, the government launched programs such as the Top-1000 Enterprises Energy Saving Program and the Ten Key Energy Saving Projects Program[1] during the 11th Five-Year-Plan[2] (FYP) (Price et al., 2011). A large amount of backward production capacities were phased out[3] (He et al., 2010). The export tax rebating rate was reduced at the start months in 2004 (Li et al., 2014). Differentiated electricity pricing[4] was initiated in 2004 and has been enforced since 2007 (Yu et al., 2015). To optimize industrial structure, the government released various policies such as the Guidance Catalogue of Industrial Restrictions (NDRC, 2005), the Decisions of Accelerating the Development of the Strategic Emerging Industries (NDRC, 2013), and the Notice of the State Council on Printing and Distributing the Industrial Restructuring and Upgrading Plan (NDRC, 2012). To upgrade the energy mix, the Renewable Portfolio Standard[5] (RPS) was introduced in 2007 (Lo, 2014). Subsidies have been given to wind power and solar power at 600 yuan/kW and 20 yuan/Wp, respectively, as well as privileges for grid connection (He et al., 2012). Polices such as the Renewable Energy Law and the Notice on Middle and Long Term Program of Renewable Energy Development were enacted (NDRC, 2008). The effects of these polices and measures were considerable.[6] The aggregate carbon intensity in China's industrial sector dropped substantially from 0.80 million tons per billion Yuan (Mt/BY, 1995 constant price) in 1996 to 0.41 Mt/BY in 2012. However, despite the remarkable achievement, it is still difficult to reliably assess which aspects of the policies and measures played a dominant role in reducing carbon intensity. Alternatively, which industrial sub-sectors were main contributors to the carbon intensity reduction? Obviously understanding these questions is beneficial for policy-makers to devise more effective mitigation polices and measures in the future.

Index decomposition analysis is an effective tool to explore factors that underlie CO_2 emission changes. It also allows for investigations of the effects of associated polices and measures (Ang, 2004). In recent years, index decomposition analysis has been widely used in studying the energy usage and energy-related gas emissions in China's industrial sector. Zha et al. (2009) analyzed the driving forces of China's industrial energy intensity from 1993 to 2003 by using the arithmetic mean Divisia index (AMDI) and the logarithmic mean Divisia index (LMDI) methods. Hasanbeigi et al. (2013) used retrospective and prospective decomposition analysis to analyze the influencing factors of China's manufacturing energy consumption from 1995 to 2020. Wu and Huo (2014) utilized an LMDI method to analyze the energy consumption changes in China's industrial and transport sector during the 11th Five-Year-Plan. Zhao et al. (2014) used an LMDI method to compare the changes in manufacturing energy consumption between China and Japan. As for the emission studies, Liu et al. (2007) quantified the driving forces of industrial carbon emissions from China's 36 industrial sub-sectors from 1998 to 2005 by using the LMDI method. The study indicated that the overwhelming contributors to the change of China's industrial carbon emissions were industry activity and energy intensity. Xu et al. (2014) applied an LMDI method to analyze the changes of sectoral greenhouse gas emissions in China from 1996 to 2012 including the industrial emissions. The study showed that the economic scale and the energy intensity were the dominant factors impacting the industrial emissions, whereas the effects from the other factors were relative minor. Yan and Fang (2015) used an LMDI method to investigate the influencing factors of China's manufacturing CO_2 emissions from 1993 to 2011. The study indicated that the economic scale was the major driving factor increasing CO_2 emissions, whereas the energy intensity was the most important diminishing factor of CO_2 emissions. Ouyang and Lin (2015) applied the LMDI method to explore the influencing factors of China's industrial carbon emissions from 1991 to 2010. Not surprisingly, the study determined that industrial activity is the major factor contributing to the increase of industrial CO_2 emissions, whereas energy intensity is the major contributor to the decrease of CO_2 emissions.

Even though a number of researchers have used index decomposition analysis to study the energy and energy-related emissions in China's industrial sector, some gaps are highlighted in the literature. First, most studies only focused on identification of the driving factors, but rarely associated the underlying policies and measures with the decomposition results. Given that a large series of policies and measures for energy conservation and emissions mitigation have been implemented in China's industrial sector over the recent years, an assessment of their effectiveness is necessary and urgent. Second, while the influencing factors were obtained, few studies went further to explore the contributions of individual industrial branches to the driving factors. As the suitability and sensitivity of various industrial sub-sectors to the mitigation policies and measures can differ, the contributions of different sub-sectors to each influencing factor can be different. As a result, in addition to the driving factor quantification, the analysis of sub-sector contributions to each influencing factor is important. Until now, only Liu et al. (2007) have investigated the contributions of industrial sub-sectors to the driving factors of carbon emissions. However, the study only explored the multi-period contribution of industrial branches to each driving factor, and failed to consider the single-period contribution analysis. As a matter of fact, the single-period analysis is also important as the industrial branches can be affected by the policies measures and programs implemented in different phases in different degree. Moreover, their study only covered the period between 1998 and 2005. The dataset are not able to reflect the recent emission changes in China's industrial sector.

To fill in the above gaps, the present study first used a Sato–Vartia LMDI method to disentangle the aggregate carbon intensity in China's industrial sector from 1996 to 2012 into three influencing factors, including the energy intensity effect, the structure effect, and the emission coefficient effect. Based on the decomposition results, the performance of the recent implemented policies and measures was evaluated. Then, both single-period and multi-period contribution of industrial branches to the change of each effecting factor were quantified by utilizing an attribution analysis recently proposed by Choi and Ang (2012). On the basis of the decomposition analysis, the attribution analysis reveals which sub-sectors were more easily regulated by the recent

[1] Refer to Zhou et al. (2010) for a detailed explanations of the two programs.

[2] The Five-Year-Plan is a strategy plan for China's economy created by the Chinese government every five years, starting in 1953. The 11th Five-Years-Plan spans from 2005 to 2010.

[3] In total, 72,000 MW of coal-fired power generators, 110 million tons of iron production capacity, 68 million tons of steel production capacity and 330 million tons of cement production capacity were retired during the 11th FYP period (Department of Climate Change, 2011).

[4] Differentiated electricity pricing is a policy designed to set different electric power pricing levels for the energy-intensive companies according to their electricity consumption levels, which means the companies with higher electricity use will be levied with higher electric power price (Li et al., 2014).

[5] The defining feature of RPS is that retail electricity suppliers are required to procure a certain quantity of renewable energy. RPS can either be completely voluntary with no compliance requirements (weak RPS) or mandatory with financial penalties (strong RPS) (Lo, 2014).

[6] Zhao et al. (2010) argue that in the past few years, energy efficiency improvement in China's industrial sector was mainly policy driven.