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Decomposition and decoupling analysis of carbon emissions from economic growth: A comparative study of China and the United States

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ABSTRACT

China and the United States (U.S) produce approximately one-third of global economic output, and emit more than two-fifths of global total carbon emissions. Comparing the decoupling of economic growth from carbon emissions in China and the U.S. can inform the development of effective mitigation strategies for those two countries and the world. In this study, we compared both the carbon emissions performance and the decoupling performance between China and the U.S. We quantified the decoupling status in China and U.S. using the Tapio decoupling indicator, and decomposed the decoupling index to explore the driving factors affecting the decoupling using the Logarithmic Mean Divisia Index (LMDI) technique. The results show that China experienced expansive coupling and weak decoupling in most years between 2000 and 2014; the U.S. experienced mostly weak and strong decoupling. In general, income and population effects restricted decoupling, whereas the energy intensity and energy mix effects promoted the decoupling process in China and the U.S. In addition, the carbon intensity effect exerted negative and positive effects on decoupling in China and the U.S., respectively.

1. Introduction

Global warming is an urgent threat around the world, and carbon dioxide (CO_2) emissions from fossil fuel combustion is driving climate change (Pachauri et al., 2014). China is the largest CO_2 emitter in the world, followed by the United States (U.S.). China and the U.S. contributed 43.3% of global carbon emissions in 2016 (BP, 2017). In 2016, China and the U.S. controlled 34% of the global economy; China is the largest developing country while the U.S. is the largest developed country (The World Bank, 2017). Economic growth is difficult to achieve without energy consumption; however, continuous fossil fuel consumption is the major driver for increased carbon emissions (Zhao et al., 2016).

In response to the Paris Accord, China pledged to hit its maximum level of CO_2 emissions around the year 2030. China committed to decrease its CO_2 emissions per unit of gross domestic product (GDP) by 60–65% from 2005 by 2030. While achievable, this emissions decrease would occur at a cost of a 6% lower economic growth annually (Deutch, 2017). However, it is essential that all countries, not just developed ones like the U.S., coordinate the link between economic growth and environmental protection. Countries must promote decoupling progress, and further develop low-carbon economies. This is particularly essential for developing countries like China and India.

This study investigated the decoupling between economic development and CO_2 emissions in China and the U.S. between 2000 and 2014. We decomposed carbon emissions changes using the LMDI model and analyzed the decoupling status by using the Tapio decoupling indicator. The decoupling index was further decomposed to identify the effect of each factor. Finally, we provide policy recommendations for both China and the U.S. to promote the decoupling process. These recommendations also apply to other developing and developed countries like China and the U.S.

2. Literature review

2.1. Research progress on sceptical to decoupling between economic growth and energy consumption

The feasibility of the decoupling between economic growth and energy consumption has been questioned by some researchers. Bithas and Kalimeris (2013) utilized the energy/GDP per capita as an indicator to estimate the energy-economic development

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decoupling effect, and obtained that decoupling effect were less optimistic than the relevant contemporary literature based on the energy/GDP indicator. Ward et al. (2016) compared historical data and modelled projections, and held that GDP cannot be decoupled from material and energy use growth. These questions focused on the decoupling effect of energy-economic growth. The substitution of one energy resource to another cleaner one does not mean the overall decrease of energy consumption. However, it is possible to envisage a decoupling scenario of GDP growth from fossil fuel use and related CO_2 emissions (Ward et al., 2016). Lenzen et al. (2016) assessed the feasibility of decoupling scenarios studied by Schandl et al. (2016) and Hatfielddodds et al. (2015), and proposed that the affluence and population can be varied within acceptable limits in common practice.

2.2. Overview of non-sceptical to decoupling theory

Other researchers have accepted as per se the potential of modern economies to perform decoupling. Several decoupling analyses have been used to investigate the relationship between economic output and environmental/carbon pressure. For example, Van Caneghem et al. (2010) studied the decoupling status of eco-efficiency indicators in Flemish industries. The results showed that climate change, energy use, and waste production impacted absolute, relative, and relative decoupling, respectively, from economic growth during 1995–2006. Freitas and Kaneko (2011) examined the decoupling of economic activity from energy-related CO_2 emissions in Brazil from 2004 to 2009, using the OECD's decoupling indicator. They found absolute decoupling in 2009. Jiang et al. (2016) analyzed the decoupling states between energy-related CO_2 emissions and economic development in the U.S. for 1990–2014. Results indicated that relative decoupling and no decoupling were the major states over the study period.

Decoupling is so crucial to the sustainable development that many researchers made efforts to studying on the decoupling in recent years. Selected paper published after 2017 are listed: (Delgado Rodríguez et al., 2018; Deutch, 2017; Luo et al., 2017; Román et al., 2018; Stål and Corvellec, 2018; Wang et al., 2018; Wang and Li, 2017; Yu et al., 2017; Zhao et al., 2017; Zhou et al., 2017). These works have a similar target – producing efficient guidance and reference to promote economic growth without carbon emission growth, and then to achieve low-carbon development and sustainable development.

2.3. Research progress on decoupling indicator

Decoupling disconnects the relationship between economic development and environmental pressure, as defined by the OECD (2002). Zhang (2000) first introduced the decoupling concept into the environmental field to study the decoupling status of China's carbon emissions from economic growth. To measure the degrees of decoupling, the OECD (2002) classified decoupling as relative or absolute. Juknys (2003) defined primary, secondary, and double decoupling categories to evaluate the decoupling of Lithuania's economy sectors. Tapio (2005) proposed a decoupling framework to explore the connection between GDP and carbon emissions in the EU15's transport sector from 1970 to 2001, based on a theory from Vehmas et al. (2003). Among these, researchers have often applied the OECD and the Tapio decoupling indicator. Decoupling resource use and environmental effects from economic growth lies at the heart of the International Resource Panel's mission. A series of decoupling investigations were carried out (UNEP, 2011), and the technological possibilities and opportunities that increasing resource productivity and accelerating decoupling were highlighted (Weizsäcker et al., 2014). So far, the decoupling indicator has been used more widely. For example, (Wang et al., 2018) use the decoupling model based on Tapio decoupling indicator Study the decoupling status between economic growth and water usage in Beijing, Shanghai, and Tianjin, China. Wu et al. (2018) systematically reviewed five decoupling index calculation methods. The research indicated that the Tapio decoupling elasticity showed greater accuracy.

2.4. Overview of decomposition techniques for decoupling process

The decomposition technique helps identify the driving forces affecting decoupling progress. There are three main types of decomposition approaches: structural decomposition analysis (SDA), index decomposition analysis (IDA), and production-theoretical decomposition analysis (PDA) (Wang and Li, 2016a; b; Zhang and Da, 2015). In particular, the LMDI model provides the "best" decomposition (Ang, 2004). Andreoni and Galmarini (2012) assessed the decoupling process of Italian economic development from carbon emissions, by applying decomposition analysis. They concluded that economic activity and energy intensity were the major factors influencing carbon emission changes. Zhang and Da (2015) combined the LMDI technique with Diakoulaki and Mandaraka's decoupling index to analyze the decoupling effect in China. They observed that lower energy intensity and cleaner energy consumption increased decoupling. Zhao et al. (2017) investigated the factors driving the decoupling of economic output and carbon emissions in China's economic sectors, using the LMDI approach. The results showed that energy intensity significantly accelerated decoupling; the industrial sector was a dominant influence, whereas the construction sector exerted a marginal effect on decoupling.

As mentioned above, the existing studies have focused primarily in conducting decoupling analyses in specific nations (Andreoni and Galmarini, 2012; Freitas and Kaneko, 2011; Jiang et al., 2016; Wang and Chen, 2015; Zhang and Da, 2015), regions (Yu et al., 2017; Zhou et al., 2017), or industrial sectors (Ren and Hu, 2012; Van Caneghem et al., 2010; Wang et al., 2017; Zhao et al., 2017; Zi et al., 2014). Few studies have compared countries with respect to decoupling; however, comparative studies are needed to adopt different measures and to developing the cooperation that will promote the decoupling process between nations.

To fill the research gap, the United States of America, the largest developed country and the second largest carbon emitter in the world, and the China, the largest developing country and the largest carbon emitter in the world are selected to conduct a comparative analysis of decoupling status and decoupling drivers. The CO_2 emission performance as well as the decoupling performance during 2000–2014 are investigated in detail. This study aims to testify the occurrence of decoupling and provide targeted recommendations for China and the U.S., and references to other developing and developed countries like the two countries.

3. Methods and data

3.1. Decoupling indicator

Decoupling breaks the linkage of "environmental bads" from "economic goods" (OECD, 2002). Tapio (2005) proposed that the decoupling indicator can be defined as:

$$\mathrm{DI} = \frac{\Delta C / C^0}{\Delta G / G^0} \quad (1)$$

In this expression, the superscript 0 denotes the initial year; $\triangle C$ refers to the change of CO_2 emissions; and $\triangle G$ refers to the change