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Investigating factors affecting carbon emission in China and the USA: A perspective of stratified heterogeneity

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ABSTRACT:

As world's top two carbon emitters, driver analysis of China and the USA helped the governments to develop policies to cut or slow down carbon emission. Many studies identified the factors affecting carbon emission in China and the USA (emitting more than 40% of the global CO_2 emission), however, few studies considered stratified heterogeneity or the interactions of factors. Here, we adopted the modified Geographical Detector tool to investigate the main drivers of carbon emission from the perspective of stratified heterogeneity. The results of this analysis showed that human economic activities in China were the dominant effect of carbon emission changes, while energy intensity contributed toward controlling the carbon emission in China. Furthermore, population growth was the most significant driving force followed by energy intensity toward controlling the carbon emission of the USA. All these factors are mutually enhancing in changing carbon emissions, while oil share with energy intensity and coal share were more significantly enhanced in China's carbon emission than other interactions. The factors of human activities and energy mix posed a more powerful effect when they mutually enhanced each other to change carbon emission compared to other enhancing interactions. This work represents a pilot scheme for a carbon dioxide emission analysis from the categorical stratified heterogeneity based on statistical methods.

1. Introduction

China is the largest CO_2 emitter and the top developing country worldwide and contributes 27.3% of the world energy-related carbon dioxide emission (BP, 2017). Furthermore, the United States of America (USA) is the world's second-largest carbon dioxide emitter as well as the world's top developed country and causes 16% of the global overall energy-related CO_2 emissions (BP, 2017). This significant share (43.3%) of carbon emission should be limited. Identifying the main drivers of these two largest carbon dioxide emitters helped to develop further carbon emission mitigation strategies.

In general, various drivers account for the energy-related carbon dioxide emission; however, a wide regional variation exists in its significance. The different economic stages, developmental patterns of the economies, and uses of energy causes a distinction in the underlying drivers of carbon emissions. Therefore, the main possible factors and the influencing mechanisms were investigated for these two top carbon emitters and energy consumers (USA and China). Furthermore, the investigation in these two typical samples, can offer new information towards the development and adjustment of more effective strategies to control the increase of energy-related carbon dioxide emissions for the rest of the world.

As is stated in Intergovernmental Panel on Climate Change (IPCC) (Blanco et al., 2018), many drivers of Greenhouse Gas (GHG) emissions are interlinked with each other. Consequently, the problems caused by this interlinking effect need to be considered. Will the driving factors affect each other and change the total carbon emission? How do they influence each other when they work together? The interaction detector of the Geographical Detector tool can address these problems and in this case, applying the

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model to analyze the CO_2 emission is of vital importance.

Before their withdrawal from the Paris agreement, the USA had been actively facing the responsibility to reduce their carbon dioxide emissions (EPA, 2014). China has also been actively working toward a carbon emission reduction and introduced corresponding policy prescriptions. The energy-related carbon emission trends of both countries have changed due to the combining and interacting systems of economic development, technology improvement, and policy adjustment. Consequently, the main drivers for the CO_2 emission changes were detected, highlighting the differences in the influencing mechanisms of both countries from the perspectives of spatial differences and stratified heterogeneity.

1.1. Overview of the CO_2 emission analysis

Detecting the main drivers of carbon dioxide emission has become a focus of socioeconomic and environmental research. Previous studies were mostly conducted using the decomposition technique, which primarily consists of two main techniques: the Structural Decomposition Analysis (SDA) and the Index Decomposition Analysis (IDA). The SDA approach was developed from an input-output (I-O) table. Of the seminal studies, Rose and Chen (1991) applied the SDA method to analyze sectoral energy consumption changes in the USA. Later, Rose and Casler (1996) reviewed the SDA evolution and highlighted the main fundamental principles when applying the structure decomposition tool. Recently, several studies applied the structure decomposition method to investigate the carbon emission from a sectoral perspective. Yuan et al. (2015) used the SDA method to compare the residential indirect carbon emission differences from the effects of urbanization, consumption ratio, and consumption structure in China and discussed the region differentiation. Wei et al. (2016) analyzed both the direct and indirect carbon emission in Beijing between 2000 and 2010 to investigate the drivers by comparing the factors from sectoral connection, technology, economic scale, and economic structure.

The IDA was also widely used because it is easier to use for the specific analysis, and the most popular technique is the Logarithmic Mean Divisia Index (LMDI). The LMDI was first introduced by Ang (Ang et al., 1998) to identify the energy demand or emission changes during a specific timespan. Ang and Liu developed the technique to solve the zero values problem (Ang and Liu, 2007). The LMDI was mainly used to analyze the energy consumption and corresponding carbon emission (Ma et al., 2017; Mousavi et al., 2017). Diakoulaki and Mandaraka analyzed the drivers of the fourteen European Union countries (Diakoulaki and Mandaraka, 2007). Mahony combined an extended Kaya identity with the log mean Divisia index (LMDI I) to analyze carbon dioxide emission changes (Mahony, 2013).

Generally, when applying decomposition methods, all possible determinants are assumed to be independent. However, full dependence (changes in one determinant cannot occur without corresponding changes in another determinant) do not exist between separate determinants in most empirical cases (Dietzenbacher and Los, 2000). Furthermore, the decomposition methods cannot reveal the possible interaction relationship of each factor; however, analyses that focus on the interaction relationship between different potential factors are required (Blanco et al., 2018). Hence, we applied the Geo-detector tool to fill this gap.

Moreover, most studies analyzed the carbon emission on a country or region scale only. However, the characteristics of influencing factors may impact the whole carbon emission changes differently. Thus, we conducted a study to investigate the relevant effects while considering the stratified heterogeneity of these factors.

Based on this, we applied the modified Geo-detector model to identify the interactions and find the drivers that focused on the spatial differences from the perspective of spatial differences in consideration of the stratified heterogeneity.

1.2. Overview of the Geographical Detector Model

Wang et al., 2010, 2016 proposed the Geographical Detector Model to assess health and environmental risks. The Geographical Detector model can address the spatial stratified heterogeneity phenomenon, which is an important portion of the spatial heterogeneity. However, the other kind of spatial heterogeneity phenomenon, spatial local heterogeneity, has been discussed in many ecology studies. Even though quantities of measures have been applied to tackle the issue, in general, three useful tools: Getis G_i (Arthur Getis, 1992), local indicators of spatial association (LISA) (Anselin, 2010) and spatial scan statistics (Kulldorff, 1997) are most widely used. However, the scopes and scales of the two spatial heterogeneity phenomena differed in the practical studies. In view of the characteristics of carbon emission changes in China and the USA, we apply the Geographical Detector Model to figure out the key drivers of CO_2 emission from the perspective of stratified heterogeneity. The Geographical Detector model primarily aimed to resolve the following four questions: (1) What are the domains of a potential risk variable? (2) Which factors should be responsible for the detected risk? (3) Which factor contributed more to the risk changes? (4) Do these factors operate independently or do they have an accessory effect? (FengCao et al., 2013) Therefore, the Geographical Detector Model was considered. Generally, four different detectors were performed when applying the model: the factor detector, the interaction detector, the ecological detector, and the risk detector. Wang and Hu developed the software GeoDetector to perform the tasks of geographical detectors (Wang and Hu, 2012). Currently, GeoDetector has been applied to different fields of research. Luo et al. analyzed land dissection density of the USA and reported that the most significant factors vary in different regions due to the differences of the geological and regional characteristics among the regions (Luo et al., 2016). Wang et al. analyzed anthropic pollution and nature and also detected their interaction relationships. The risk and factor detector was used to find risk spots and clarify the main influencing factor. Moreover, the ecological and interaction detectors were applied to further detect the influencing system (Wang et al., 2010).

Most of the studies on the Geographical Detector Model were used to analyze geographical distribution differences during one single year or the change between a final year and a base year in a specific area. However, since the changing trend of carbon emissions is a long-term process, all the years during a period should be considered. Thus, it is necessary to conduct year-to-year stratified sampling of the changes in carbon emissions in different years with a focus on the characteristic differences. Hence, we modified the original Geographical Detector Model to improve the pertinence in discussing the CO_2 emission issues by taking the changing process of carbon emission and the possible factors characteristics differences in various years into account. Based on the modified Geographical Detector Model, we comparatively analyzed the energy-related CO_2 emission in China and the USA and detected the differences in dominant drivers.

2. Methods and data

2.1. Materials and methods

The geographical detector tool was mainly used to test the spatial stratified heterogeneity and the influencing drivers of a