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Convergence of carbon emissions intensity across Chinese industrial sectors

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A B S T R A C T

The convergence of carbon emissions in the industrial sector is an important prerequisite for achieving peak carbon emissions in China. This study investigates the carbon emissions intensity convergence of 24 industrial sectors in China between 1995 and 2015 based on an environmental performance index method and the convergence model. The results find that beta-conditional convergence exists across the carbon intensities of all industrial sectors by considering capital intensity and per-capita sectoral value added. This finding indicates that the carbon intensities of all sectors converge to different steady levels and are influenced by the two considered control variables. A decrease in the capital intensity or increase in the per-capita value added increases the degree of carbon intensity convergence, but the effect of per-capita value added is greater. Additionally, club convergence analyses show that there are two stronger convergent clubs of carbon intensity for 20 sectors, but the convergence evidence of the remaining four sectors is relatively weak.

1. Introduction

To address the threat that climate change poses to the survival of humanity, global governments are making considerable efforts to reduce carbon emissions. As a responsible country, China has committed to reducing its carbon intensity (CO_2 emissions divided by gross domestic product (GDP)) to 60–65% of the 2005 level and achieving peak carbon emissions by approximately 2030, with efforts to achieve that peak earlier (Xinhuannet, 2015). The peak goal is the first promise of overall emission reductions in China. Driven by this ambitious goal, the growth of China's carbon emissions has slowed in the past two years (Jackson et al., 2016). However, as the world's largest emitter, China must further develop practical strategies to achieve the goal of reducing carbon emissions. Industrial sectors are the main source of Chinese emissions, accounting for 84.0% (including the construction sector) of total energy-related emissions in 2014 (IEA, 2016). Therefore, the convergence of carbon emissions in the industrial sector to a stable level is critical to meeting China's peak emission objectives.

Due to the different natures of the production processes and characteristics of different economic sectors, the carbon intensities of different sectors vary. According to the *Action Plan of Industries Addressing Climate Change (2012–2020)*, key industries such as steel, non-ferrous metals, petrochemical and etc. have been set different goals of carbon intensity decline. Therefore, to design and implement appropriate sectoral economic, energy, and carbon reduction policies, we should recognize the dynamic trends and convergence patterns of carbon intensity across sectors. Furthermore, the existence of convergence in carbon intensity is a necessary condition for reaching a plateau or peak in national total CO_2 emissions (Jobert et al., 2010). Thus, it is motivated to examine the existence of carbon intensity convergence among China's industrial sectors.

Based on long-term economic growth in the neoclassical model, the convergence hypothesis is typically used to explain the substantial heterogeneity in economic growth (Quah, 1996; Solow, 1956) or income performance (Ben-David, 1996) across countries. Recently, carbon emissions convergence has been widely investigated in a growing number of studies as global warming has become a popular research topic. A per-capita scheme would allocate emission rights (Romero-Ávila, 2008). Therefore, early studies have mainly focused on verifying the convergence

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hypothesis for cross-county per-capita CO_2 emissions, especially among members of the Organization for Economic Cooperation and Development (OECD) and industrialized countries. For example, using non-parametric techniques, Nguyen-Van (2005) obtained similar convergence results for 26 industrial countries from 1966 to 1996. By applying a new version of the panel stationarity test, Romero-Ávila (2008) reconfirmed the per-capita CO_2 emissions convergence for 23 OECD members from 1960 to 2002. Similar convergence results were obtained in studies by Jobert et al. (2010) and Herrerias (2012).

However, with the expansion of the study period, the evidence for per-capita emissions convergence becomes uncertain. For example, Lee et al. (2009) discovered that per-capita CO_2 emissions in 21 OECD countries included a mixture of $I(0)$ and $I(1)$ processes, and 14 out of 21 OECD countries exhibited divergence from 1960 to 2000. By implementing a variety of stationarity and unit root tests, Barassi et al. (2008) illustrated that per-capita CO_2 emissions did not converge among OECD countries from 1950 to 2002. Similar uncertainty was also observed in test results by Yavuz and Yilanci (2013) for G7 countries from 1960 to 2005, and Presno et al. (2015) for 28 OECD members from 1901 to 2009.

In addition to exploring emissions convergence of whole sample countries, the club convergence among subsamples is also studied by considering the diversity and economic levels of countries. For instance, Aldy (2006) claimed that convergence existed among 23 member countries of OECD but that there was little evidence of convergence for a sample of 88 countries from 1960 to 2000. Panopoulou and Theologos (2009) found that the per-capita CO_2 emissions of 128 countries globally could be described as two separate convergence clubs that evolved to different steady states in the recent era. Similar subsample convergence results can be reported by Criado and Grether (2011), for 166 world areas from 1960 to 2002, and Li and Lin (2013), for 110 countries from 1971 to 2008.

To effectively share China's overall emission reduction targets across provinces, some studies have discussed the emissions convergence of regions. For example, Wang and Zhang (2014) discovered that the per-capita CO_2 emissions in six sectors converged across 28 provinces from 1996 to 2010. Similar provincial convergence results were reported by Yang et al. (2016). Huang and Meng (2013) identified a convergence trend in the per-capita CO_2 emissions of urban China from 1985 to 2008. Additionally, Wu et al. (2016) confirmed convergence in 286 Chinese cities from 2002 to 2011. In addition to exploring the convergence of per-capita carbon emissions, empirical studies of China have investigated carbon intensity trends. For instance, Wang et al. (2014) provided strong evidence of divergence in China and three convergence clubs in terms of the carbon intensity from 1995 to 2011. Hao et al. (2015) confirmed that stochastic convergence and β -convergence were associated with the CO_2 intensity across Chinese provinces. Additionally, Zhao et al. (2015) concluded that the CO_2 intensity converged across 30 provinces from 1990 to 2010. Related studies on CO_2 convergence of cross-country, cross-region, and cross-sector are summarized in Table A1.

Existing studies of regional carbon emissions convergence consider spatial heterogeneity, which may be helpful in understanding the trends of regional carbon emissions and implementing specific emission reduction policies in different regions. However, the final bearers of the carbon emissions reduction burden are the enterprises that belong to the different sectors, especially in the case of China, which has a complete sectoral economic system. To understand sectoral emissions characteristics and design a specific policy to reduce carbon emissions from economic sectors, many studies have used various decomposition analyses to explore the factors and forces driving emissions. For example, Kopidou and Diakoulaki (2017) used the Logarithmic Mean Divisia Index (LMDI) method to decompose the driving factors of industrial CO_2 emissions in Southern European countries. Based on a three-dimensional decomposition model, Xu and Tao (2018) decompose the carbon intensity of China's power industry. Similar factor decomposition works also can be found in studies by Long et al. (2015) and Zhao et al. (2017). In addition, the sectoral carbon abatement potential (Yu et al., 2015, 2016; Zuberi and Patel, 2017) and costs (He and Qiu, 2016; Xie et al., 2017) have been extensively studied in recent years.

Based on the above examples, existing studies have mainly focused on the convergence of cross-country, provincial, or city-level carbon emissions, but few researches have focused on the emissions convergence of economic sectors. To explore the carbon intensity of convergence from the perspective of the Chinese economic sector, we must understand the dynamic characteristics and evolution of carbon emissions in the different sectors in China and consider the heterogeneous structure of the economy by providing support for the formulation of sectoral reduction policies. For example, reducing the outputs of sectors in which the carbon intensity is either not convergent or weak to converge would be a good way to decrease emissions, especially when combined with China's current macroeconomic policy of economic restructuring.

Wang and Zhang (2014) examined carbon convergence in six sectors of China; however, their study merged all the sectors in the secondary industry into two sectors (industry and construction) and did not investigate the convergence of industry subsectors in detail. Furthermore, their study of convergence focused on sectoral per-capita emissions without considering the efficiency of carbon emission controls in sectoral production. Although Moutinho et al. (2014) and Brännlund et al. (2015) studied convergence across sectors in Portugal and Sweden, respectively; their studies did not focus on China's scenario. Therefore, to fill this research gap, the present study focuses on exploring the convergence of the carbon intensity across 24 industrial sectors in China from 1995 to 2015. In addition, the heterogeneous slope coefficients with the common correlated effects mean group (CCEMG) method is applied to estimate the coefficients of the proposed model, as the CCEMG estimator allows for cross-sectional dependence and is robust for unbalanced panels (Pesaran, 2006). Concerning the potential spurious regression caused by non-stationary series, one solution is the cointegration technique (Halicioglu and Ketenci, 2016). The other approach is CCEMG estimator, which is robust to panels with structural breaks or unit roots (Kapetanios et al., 2011).

Investigations of the carbon intensity convergence of industrial sectors in China are helpful for understanding carbon emissions trends and implementing specific reduction policies. The contributions of this study are follows. First, the convergence of the carbon intensity across all industrial sectors is investigated, rather than at the geographical level such as countries, provinces or cities. The results of the investigation are valuable for specifying a systematic policy of carbon emission reduction for all subsectors of the secondary industry. Second, the effects of the relevant control variables on the sectoral convergence state level are explored, and the key factors that influence the convergence of the carbon intensity are identified. These results potentially provide decision-making support for implementing specific and refine emission reduction strategies for different subsectors. Third, the application of the CCEMG estimation method solves the spurious regression that may result from non-stationary series, as it permits the existence of cross-sectional dependence and is robust to panels with structural breaks or unit roots (Kapetanios et al., 2011). Finally, not only all industrial sub-sectors, but also the convergence of the clustering subgroups is discussed via the PS's club convergence method. In our limited literature review, club convergence across