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# Convergence of carbon dioxide emissions in Chinese cities: A continuous dynamic distribution approach

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## HIGHLIGHTS

- Spatial dynamics of per capita carbon dioxide ($CO_2$) emissions in 286 Chinese cities.
- A continuous dynamic distribution approach and panel data.
- Multimodality is found in the ergodic distribution of the full sample.
- Significantly different dynamics among various city groups.

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## ABSTRACT

This paper investigates the spatial dynamics of per capita carbon dioxide ($CO_2$) emissions in China. The analyses are conducted by employing a continuous dynamic distribution approach and panel data of 286 cities at the prefecture and above-prefecture level. The results show that per capita $CO_2$ emissions tend to converge during the sample period of 2002–2011. However, multimodality is found in the ergodic distribution of the full sample. It is also found that there is more persistence in cities with low per capita $CO_2$ emissions, and more mobility in cities with high per capita $CO_2$ emissions. The analyses also show that the dynamics of per capita $CO_2$ emissions are significantly different among various geographical, income and environmental policy groups. The conditional distribution analyses indicate that multimodality cannot be explained independently by any one of the two factors, namely geographical location or income level. The findings in this study may have important policy implications for $CO_2$ abatement in China.



## 1. Introduction

After more than 30 years of rapid economic growth, China's per capita income increased dramatically. However, this growth has led to a large increase in energy consumption and hence $CO_2$ emissions. Low efficiency in energy use coupled with an economic structure dominated by the manufacturing sector has further pushed up the level of $CO_2$ emissions. Since 2007 China has surpassed the US to become the largest $CO_2$ emitter in the world. The Chinese government is therefore facing intense international pressure to reduce emissions. To respond to global climate change causes and for the purpose of China's own sustainable development, the Chinese government has planned to reduce $CO_2$ intensity (the ratio of $CO_2$ emissions over GDP) by 17% during the 12th Five Year Plan (FYP, 2011–2015). Furthermore, in early 2014, the Chinese government announced to end growth in aggregate $CO_2$ emissions by 2030.

To meet the above-mentioned targets, it is important to understand the spatial distribution and evolution of $CO_2$ emissions in the economy. Information about the latter could be used for predicting future $CO_2$ emissions and designing environmental policies. For example, evidence of emission divergence or club convergence across city groups may suggest the lack of sustainability and hence environmental regulation should be targeted at specific cities or city groups. Internationally, this issue has received a lot of attention in the field of $CO_2$ emissions research. The pioneering work includes Strazicich and List (2003). Recently Pettersson et al. (2014) presented a review of the literature. Some studies also investigated the convergence of $CO_2$ emissions in China (Wang and

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Zhang, 2014; Wang et al., 2014; Hao et al., 2015a,2015b; Zhao et al., 2015). However, these studies are based on traditional convergence approaches which involve the concepts of sigma, beta and stochastic convergence. These approaches can help gain important insights into the evolution of $CO_2$ emissions in general, but provide little information for the entire shape of the spatial distribution and its dynamics. For example, traditional convergence approaches can verify the existence of convergence clubs, but give no information about their formation and evolution. In addition, traditional approaches completely neglect the possibility of intradistribution mobility, namely the relative position changes in term of $CO_2$ emissions. Finally, most existing studies of China's $CO_2$ emissions are based on provincial data. There are two problems. The first is that Chinese prefectures in a province may vary a lot in terms of $CO_2$ emissions. Thus the analysis based on provincial data provides little information about intra-provincial $CO_2$ emissions. Second, there are only 31 provincial administration regions in China. Studies based on provincial data always encountered the problems of a small sample.

This paper aims to investigate the dynamics of the spatial distribution of per capita $CO_2$ emissions in 286 Chinese prefecture and above-prefecture level (PAA) Cities. It makes several contributions to the existing literature: First, a database of $CO_2$ emissions in 286 Chinese cities is constructed for the first time. This database provides much more information than a provincial level data set. In China, the majority of energy usage and $CO_2$ emission generation occurs in urban areas. For example, Dhakal (2009) indicates that urban areas consumed 84% of China's total commercial energy in 2006. Hence, the mitigation of urban related $CO_2$ emissions is the key part of $CO_2$ abatement in China. Second, a continuous dynamic distribution approach is adopted to investigate the dynamics of per capita $CO_2$ emissions in China. This dynamic distribution approach is different from the conventional approaches. It is completely data-driven and imposes no assumptions on the model. More importantly, this approach can provide the dynamics of the entire shape of the distribution. The analyses are conducted using the full sample and across different subgroups, namely geographical, income level and environmental groups. Third, this paper also explores the factors which may influence the distribution dynamics of per capita $CO_2$ emissions in China through conditional distribution analysis. In particular, it is found that the multimodality in the ergodic distribution cannot be interpreted by any of the two factors, namely geographical location and income level. Finally, this paper also contributes to the debate about the environmental Kuznets curve (EKC) in recent years. The finding of convergence supports the existence of EKC among Chinese cities. The unimodality identified in the key cities of environmental protection may imply that environmental regulation is an important factor for emission control.

The rest of this paper is arranged as follows. Section 2 provides a brief review of the related literature. In Section 3, the research method is discussed. Section 4 describes the data. Section 5 presents the empirical results and discussions. Section 6 examines conditional distribution dynamics followed by concluding remarks and discussion of policy implications in Section 7.

## 2. Literature review

The research on convergence of PCE can be broadly grouped into two strands. The first strand uses conventional parametric approach to examine the existence of absolute, conditional convergence and stochastic convergence. Strazicich and List (2003) investigated both stochastic and conditional convergence of PCE across 21 industrial countries with panel unit root tests and cross-section regressions. Their results support the convergence of PCE in these countries. Romero-Ávila (2008) also found strong evidence of convergence among 23 OECD countries with a new version of the panel stationarity test. Jobert et al. (2010) examined the convergence of PCE among 22 European countries over the period 1971–2006 with a Bayesian shrinkage estimation method and found evidence for absolute convergence. Some papers have tried to include more samples in PCE convergence studies. Westerlund and Basher (2008) examined the convergence of PCE among 28 developed and developing countries during 1870–2002. They found strong evidence for convergence. However, Barassi et al. (2008) employed a battery of stationarity and unit root tests from both individual country data series and panel set with a sample of OECD countries during 1950–2002. They found no evidence for convergence in their samples. Panopoulou and Pantelidis (2009) used a large sample of 128 countries during 1960–2003 to examine convergence of PCE. Their results show that PCE tends to converge in the early years, but converges to two separate clubs in the later years.

The second strand of literature adopted non-parametric approaches to investigate the dynamic distribution of PCE. This strand of research is inspired by the works of Quah (1993,1996a,1996b,1997) on the convergence of economic growth. Van (2005) used a nonparametric distribution approach to examine the convergence in PCE among 100 countries during 1966–1996. The results support the convergence among industrial countries, but no evidence of convergence for the full sample. However, this paper does not estimate long run distribution (ergodic distribution). Aldy (2006) used a Markov transition matrix approach and found that emissions tend to diverge in the future among 88 countries in a global sample over 1960–2000. Ezcurra (2007), using a nonparametric stochastic kernel approach, examined the spatial distribution of PCE in 87 countries during the period 1960–1999. He found that cross-country disparities in PCE declined during their sample period and the intradistribution mobility level is low. Criado and Grether (2011) employed a similar approach to investigate the convergence of PCE among 166 world areas for the period 1960–2002. Their results show divergence of PCE in the long run.

With the increasing importance of $CO_2$ emissions in China, more and more studies have focussed on environmental issues in Chinese economy. Wang and Zhang (2014) examined the β-convergence, stochastic convergence and sigma convergence of PCE in six sectors across 28 provinces in China during 1996–2010. They found evidence for convergence in all sectors across the provinces. They also found that the factors affecting PCE vary across sectors. Huang and Meng (2013) used a spatio-temporal model to study the convergence of PCE in urban China and also found evidence of convergence. However, their urban data are aggregated at provincial level. Because the Chinese government always uses $CO_2$ emission intensity (ratio of $CO_2$ emissions to GCP) as an important indicator in $CO_2$ abatement, some research focuses on the convergence of carbon intensity in China. Wang et al. (2014) provided evidence for club convergence in $CO_2$ emission intensity by using provincial data for the period 1996–2011. They also showed that per capita GDP, energy consumption structure, energy intensity, and initial levels of economic development are the major determinants of club convergence. Hao et al. (2015a, 2015b) examined the convergence of $CO_2$ emission intensity with provincial panel data during 1995–2011. They found evidence for stochastic convergence and β-convergence among Chinese provincial samples. Zhao et al. (2015) employed a spatial dynamic panel data model to investigate provincial convergence of $CO_2$ emission intensity during 1990–2010. They found evidence that $CO_2$ emission intensity converges across provinces in China. Li and Lin (2015) studied the convergence of energy efficiency with $CO_2$ emissions with provincial panel data. Hao et al. (2015a, 2015b) used 113 cities