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Convergence of carbon intensity in the Yangtze River Delta, China

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A B S T R A C T

As China's industrialization and urbanization have grown rapidly in recent years, China's CO_2 emissions rose from 3405.1799 Mt to 10,249.4630 Mt from 2000 to 2013, and it has reached the highest levels in the word since 2006. Chinese government has emphasized the importance of reducing carbon emissions and set the target of reducing carbon intensity to 60–65% of 2005 levels by 2030. Investigating the convergence of carbon intensity can identify the convergence rate, which is helpful in guiding allocations of carbon intensity reduction. The Yangtze River Delta is one of the key carbon emission regions in China, with higher urbanization levels and larger carbon emissions; thus, we employed prefecture-level panel data derived from grid data between 2000 and 2010 to examine whether the convergence of carbon intensity exists across prefecture-level cities in the Yangtze River Delta. Spatial panel data models were utilized to investigate β-convergence of carbon intensity. The results indicated that carbon intensity showed divergence during 2002–2004 and σ-convergence over other periods (2000–2002 and 2004–2010). Carbon intensity exhibited stochastic convergence, indicating that the shocks to carbon intensity relative to the average level of carbon intensity are only transitory. There was a spatial spillover effect and β-convergence of carbon intensity, suggesting that prefecture-level cities with higher carbon intensity would decrease rapidly in the Yangtze River Delta. Our results highlight the importance of considering the present state of carbon intensity, spatial factors, and socioeconomic factors such as industrial structure and economic levels during allocation planning for reducing carbon intensity.

1. Introduction

Carbon dioxide is one of the key greenhouse gases causing global warming; most world governments have recognized the risk of global warming and urgency for carbon reduction. With rapid industrialization and urbanization, China's CO_2 emissions were 3405.1799 Mt in 2000, and it increased rapidly with the average growth rate of 8.2% from 2000 to 2013. China's CO_2 emissions are at their highest since 2006 (Gregg, Andres, & Marland, 2008). During the same period of 2000–2013, China's contribution to global carbon emissions rose from 13.7% to 28.6% (Fig. 1) (World Bank, 2016). To mitigate carbon emissions and global warming, China has made different environmental policies and taken effective measures (Li & Lin, 2016; Wu, Wu, Guo, & Cheong, 2016). In particular, China has raised a target of decreasing carbon intensity (CO_2 emissions divided by gross domestic product (GDP)) to 40–45% of 2005 levels by 2020 (Li et al., 2016; Qiu, 2009). In the Twelfth Five-Year (2011–2015) Plan drafted by China's State Council, the target of carbon emission were allocated to the provinces for the first time (Hao, Liao, & Wei, 2015a). China pledged that the peak of CO_2 emissions would achieve around 2030, carbon intensity would decline to 60%–65% of 2005 levels by 2030 in China (National Development and Reform Commission of China, 2015). The allocation of carbon emission reductions has attracted the attention of scholars (Liao, Zhu, & Shi, 2015; Yu, Wei, & Wang, 2014; Zhang, Wang, & Da, 2014), but there are relatively few studies from the perspective of convergence for carbon intensity (Hao et al., 2015a; Wang, Zhang, Huang, & Cai, 2014b). Many climate policies assume that there is convergence (McKibbin & Stegman, 2005; McKibbin, Pearce, & Stegman, 2007; Pettersson, Maddison, Acar, & Söderholm, 2014). The convergence of carbon intensity can

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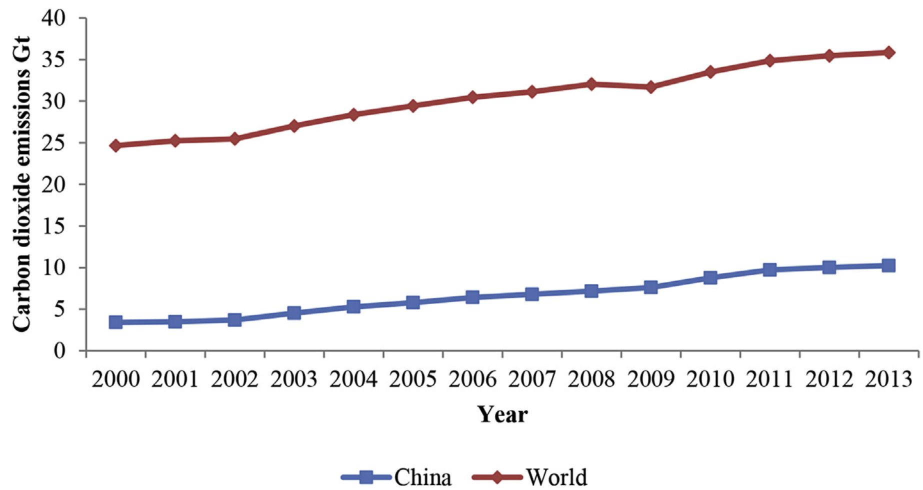

Fig. 1. Carbon dioxide emissions in China and the world from 2000 to 2013 Data source: World Bank http://data.worldbank.org.cn/indicator/EN.ATM.CO2E.KT.

provide an important reference for the equal allocation of carbon intensity targets and contribute to the projections of carbon intensity (McKibbin & Stegman, 2005; Pettersson et al., 2014). Meanwhile, the existing convergence of carbon intensity is helpful to make better environmental policies and it is a necessary condition to achieve the peak of carbon emission (Jobert, Karanfil, & Tykhonenko, 2010; McKibbin & Stegman, 2005). Analyzing the convergence of carbon intensity is helpful to cognize the change mechanism of carbon intensity and to set evidence-based policies for carbon intensity targets. Convergence of carbon intensity is of particular concern to policymakers in China, and government establishes some important targets of decreasing carbon intensity (Li & Lin, 2016; Wu et al., 2016). Instead of equal allocation of carbon intensity to each province, the allocation of carbon intensity to prefecture-level city can be more effective (Wu et al., 2016). Therefore, investigation of the convergence of carbon intensity is important for policymakers to provide suggestions in allocating carbon intensity targets according to carbon intensity rules.

Solow (1956) first proposed the theory of convergence in 1956, which has become important in modern economic growth research (Hao, Zhang, Zhong, & Li, 2015b). To our knowledge, Strazicich and List (2003) probably made the first attempt to test the conditional and stochastic convergence in 21 industrial countries during the period of 1960–1997 and found that there was significant convergence. Pettersson et al. (2014) reviewed the development literature of the convergence. The research on the scale of carbon convergence mainly focuses on countries (Fallahi & Voia, 2015; Jobert et al., 2010; McKitrick & Wood, 2013; Ordás Criado & Grether, 2011) or provinces (Hao et al., 2015a; Wang & Zhang, 2014; Yang, Zhang, Sheng, & Shackman, 2016). For example, Ordás Criado and Grether (2011) investigated the convergence of per capita CO_2 in 166 world areas during 1960–2000 and found that there were different convergence states during different periods. Wang and Zhang (2014) investigated the convergence of CO_2 in China's six sectors in provincial level during 1996–2010 and found that there was convergence in these sectors.

Different methods have been developed to investigate the convergence of carbon emissions in recent years. The system generalized method of moments (GMM) was utilized by Yang et al. (2016) to investigate the convergence of CO_2 emissions during 1998–2012 and found no convergence. Bayesian shrinkage estimation (BSE) was applied by Jobert et al. (2010) to examined the convergence of CO_2 emissions during 1971–2006 and they found that there was absolute convergence. Semi-parametric and non-parametric models were employed to investigate the convergence of nitrogen oxides and sulfur oxides in 25 European countries during 1980–2005 (Ordás Criado, Valente, & Stengos, 2011). The log *t* test was used by Wang et al. (2014b) to verify the convergence of carbon intensity in China during 1995–2011 and they found that there was divergence at the national level but convergence at the provincial level. Spatial lag model (SLM) was utilized by Huang and Meng (2013) to investigate CO_2 emissions convergence and they found that the convergence rate showed an increasing trend when considering spatial effects. Spatial autoregressive (SAR) model and spatial error model (SEM) was used by Yu (2012) to verify the convergence of Chinese energy intensity and the result showed absolute β-convergence across provinces.

Although the existing studies have focused on the convergence of carbon emissions (Evans & Kim, 2015; Pettersson et al., 2014; Wang & Zhang, 2014; Wu et al., 2016), there were three major limitations. First, the research scale mainly focuses on countries (Fallahi & Voia, 2015; McKitrick & Wood, 2013; Ordás Criado & Grether, 2011) or provinces (Hao et al., 2015a; Wang & Zhang, 2014; Wang et al., 2014b). Second, previous researches on carbon emissions convergence have focused on carbon emissions per capita (Jobert et al., 2010; Pettersson et al., 2014); however, few have investigated the convergence of carbon intensity (Hao et al., 2015a; Wang et al., 2014b; Zhu et al., 2014). Third, most studies have ignored the effects of spatial factors on carbon emission convergence, which may increase the biases of results.

To address these knowledge gaps, the current paper utilizes spatial econometric models to examine the convergence of carbon intensity in the Yangtze River Delta (YRD) during the period of 2000–2010, using the prefecture-level city as the basic research unit and considering spatial spillover effects and spatial dependence. To our knowledge, this is the first attempt to investigate the convergence of carbon intensity across prefecture-level cities using grid data in the YRD. Compared with provincial data, prefecture-level city data can provide more accurate and detailed results; meanwhile, prefecture-level cities are the main source of carbon emissions. In addition, we investigate the convergence of carbon intensity rather than carbon emissions per capita, which can better assist policymakers in allocating the reduction targets of carbon emissions. Furthermore, we consider spatial spillover effects and spatial dependence, utilizing spatial econometric models that examine β-convergence, better simulating the actual values.

The paper investigates these questions: (1) Is there convergence of carbon intensity during the period of 2000–2010 in the YRD? (2)