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# Province-level convergence of China's carbon dioxide emissions

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## HIGHLIGHTS

- Find province-level convergence of $CO_2$ emissions in China.
- Use a novel, dynamic spatial dynamic panel data to evaluate convergence.
- Rate of convergence is higher with the spatial econometric models.
- Province-level $CO_2$ emission intensities are spatially correlated.

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## ABSTRACT

This study offers a unique contribution to the literature by investigating the convergence of province-level carbon dioxide emission intensities among a panel of 30 provinces in China over the period 1990–2010. We use a novel, spatial dynamic panel data model to evaluate an empirically testable hypothesis of convergence among provinces. Our results suggest that: (1) $CO_2$ emission intensities are converging across provinces in China; (2) the rate of convergence is higher with the dynamic panel data model than the cross-sectional regression models; and, (3) province-level $CO_2$ emission intensities are spatially correlated and the rate of convergence, when controlling for spatial autocorrelation, is higher than with the non-spatial models.



## 1. Introduction

Understanding the distribution of carbon dioxide emissions ($CO_2$) through time and space can help policy makers in designing policies to combat climate change. The geographic distribution of $CO_2$ emissions does not affect the global climatic impact, but it does affect the political economy of negotiating multilateral agreements [1]. Global climate change is an international problem in scope, yet domestic or regional policies can be implemented to mitigate $CO_2$ emissions. In the last two decades, carbon dioxide emission intensities (defined as the ratio of carbon dioxide emissions to gross domestic product (GDP)) across the provinces in China have been declining year-by-year as illustrated in Fig. 1. A large number of past studies have examined the factors that have led to the decline in $CO_2$ emission intensity. For example, Liddle [2] found that improvements in technology, changes in the country's economic structure, and energy efficiency accounted for most of the decline. Zhao et al.'s [3] findings suggest that technological improvements in energy consumption and transportation as well as an increase in population density have led to the reduction in $CO_2$ emission intensity in China. Others have found that structural changes in China's economy (including a decline in emissions in the country's secondary sector) have led to the reduction in emission intensities [4–8].

Still other studies have found contrasting results and suggest that carbon emission intensities are not declining but rather are expanding. For example, Steckel et al. [9] find that energy intensity (defined as the ratio of energy consumption and production to GDP) is declining, and find that carbon intensity (defined as the ratio of carbon dioxide emissions to energy consumption and production) is increasing through time. The difference between our findings and that of Steckel et al. [9] are due to three primary factors. Steckel et al. [9] define carbon intensity differently than we do in the current study – our definition of "carbon emission intensity" is consistent with China's carbon reduction strategy as outlined in the national government "five year plan."

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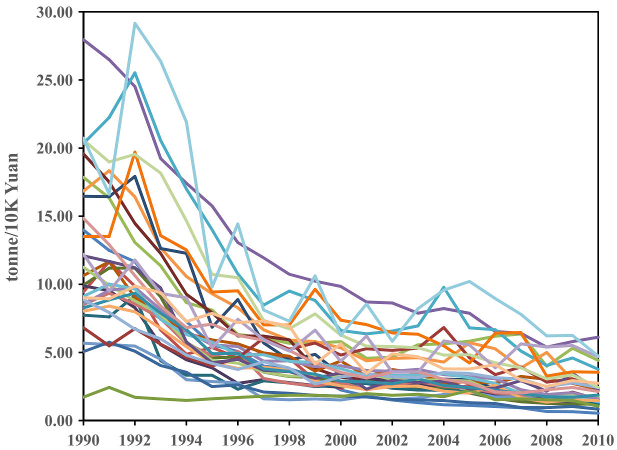


**Fig. 1.** $CO_2$ emission intensity of each province in China, 1990–2010.


**Fig. 2.** Overall $CO_2$ emission intensity of China, 1990–2010.

The first difference is that Steckel et al. [9] obtain the carbon emission data from the International Energy Agency's 2009 World Energy Statistics database. Our carbon emissions data, on the other hand, are based on province-level energy consumption, which we obtain directly from China's Statistical Energy Yearbook. This consumption data is converted to carbon dioxide emissions by multiplying (or scaling) each of the primary fossil fuel types by a carbon intensity coefficient (a more concise definition is provided in Eq. (1) below). Our conversion of carbon dioxide emissions is consistent with the 1996 Intergovernmental Panel on Climate Change's "Guidelines for National Greenhouse Gas Inventories" [10] and the Carbon Dioxide Information Analysis Center [11].

Another difference is that our study defines carbon intensity as the ratio of carbon dioxide emissions to GDP, whereas Steckel et al. [9] defines intensity as the ratio of carbon to energy consumption. Therefore, our definition of carbon intensity is closer to their definition of energy intensity, which they have found to be declining over the period 1975–2011.

The last difference is that Steckel et al. [9] conduct a decomposition analysis, akin to the IPAT and Kaya identity literatures [12,13], of China's emissions, whereas the current study uses econometric (statistical) methods to exam the country's emissions. Decomposition methods are useful for examining the different factors affecting emissions; however, such methods are not statistical (i.e., there are no stochastic elements in the decomposition) and therefore are arguably more limited than econometric methods as explored in the current study. For a more complete discussion of the difference between decomposition analysis and econometric methods in regards to $CO_2$ emissions, the reader is referred to [14].

Therefore, whether China's $CO_2$ emissions are decreasing or not depends on the very definition of carbon (dioxide) emission intensity. Like Steckel et al.'s [9] definition of China's energy intensity, we find that the country's aggregate carbon emission intensities have been declining since the mid-1970s. However, an examination of China's national-level emissions does not necessarily reveal any information about the country's province-level emissions. That is, are some province's emissions increasing while others are decreasing? A relatively easy method to compare the contrast trends in province-level emissions is to examine whether such emissions are converging or diverging through time. The convergence of China's province-level $CO_2$ emission intensities has received little attention in the literature, and is thus the main focus of the current study.

In accordance with the Copenhagen Accord, China set the goal to reduce its carbon dioxide emissions per unit of GDP (or carbon intensity) by 40–45% of 2005 levels by 2020. Although $CO_2$ emission intensities have been declining year-by-year in China as shown in Fig. 2, the country still has a long way to go to achieve its reduction goal. If China were to formulate a national climate change policy to ratify such an international agreement then it must begin to look inward to determine the sources and distribution of emission intensity. With this look inward, policy makers may be interested in determining how the distribution of province-level emission intensity is changing over time. Convergence in energy intensity could imply that technological differences across regions diminish over time [15–21]. This study seeks to determine interregional differences in technology tend to dissipate or increase over time. If differences diminish naturally over time then policymakers may be less worried about a mitigation scheme. If the differences tend to perpetuate or grow over time (which implies a lack of diffusion of energy-related technologies) then it may be too difficult to reach the country's mitigation targets.

It is a matter of debate whether this study's measure of carbon emission intensity is the correct metric to use to analyze the convergence of province-level $CO_2$ emissions. In other words, would our findings of convergence change if we use a different metric? As identified above, the particular metric we use is consistent with China's five-year plan. Therefore, analyzing the convergence of province-level emissions using this particular metric is appropriate in this context as it is corresponds with China's existing $CO_2$ mitigation policies. We leave sensitivity analyses of convergence, based on different metrics or measures of $CO_2$ emissions, for future research.

According to Liddle [2], there are a number of factors that affect a country's aggregate level of energy intensity (and by extension its carbon intensity), including its economic structure, sectoral composition, fuel mix, and efficiency in conversion and end-use of energy. He argues that if the economic structure dominates then trade may lead to a divergence in energy intensity; however, if technology (energy efficiency) dominates, then trade may facilitate energy efficiency practices, and could lead to convergence in intensity [2]. In the current study we are not engaging in a decomposition analysis to determine the explicit factors affecting convergence or divergence; rather we are exploring the province-level trends of $CO_2$ emission intensities (while controlling initially for space and subsequently for economic growth as well) to determine if the paths are converging. Hence, if we find evidence of province-level convergence in emissions then it implies perhaps that technological developments, coupled with trade, are encouraging best efficiency practices and thereby leading to a convergence in energy intensity among provinces.