



## Distribution dynamics of energy intensity in Chinese cities

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### HIGHLIGHTS

- The behaviour of energy intensity across Chinese cities is investigated.
- The dynamic distribution approach is used.
- The results support the existence of convergence.
- However, bimodality is the dominant characteristic in the long-term distribution.

### ARTICLE INFO

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### ABSTRACT

This paper examines the dynamic behaviour of energy intensity across Chinese cities. It employs a dynamic distribution approach which takes economic size into consideration. The results support the existence of convergence in terms of energy intensity among Chinese cities during the sample period. However, bimodality is the dominant characteristic in the long-term distribution using the full sample. The results also show that the distribution dynamics of energy intensity differ greatly among city groups in terms of geographical location, environmental policy, and population size. Weighting by economic size does not change the convergence trend of energy intensity, but has a significant influence on the long-term distribution. Neglecting economic size may overstate the energy reduction performance in Chinese cities. Furthermore, the results also suggest that geographical location, income level, and city population size have a significant impact on the spatial distribution dynamics of energy intensity. However, the formation of convergence clubs is complicated and thus requires further investigation.

### 1. Introduction

Understanding the spatial distribution dynamics of energy intensity is of great importance in predicting future energy consumption and designing environmental policies. In recent years, the convergence of CO<sub>2</sub> emissions has received much attention since the pioneering work of Strazicich and List [1] (see Pettersson et al. [2] for a review of the literature). However, the dynamics of energy intensity received much less attention than those of CO<sub>2</sub> emissions. Only a few studies have focused on this issue (Markandya et al. [3]; Ezcurra [4]; Liddle [5]; Le Pen and Sévi [6]; Liddle [7]; Herrerias [8]; Kiran [9]; Mulder et al. [10]; Zhang and Broadstock, [11]; Burnett and Madariaga, [12]; Karimu et al. [13]). Energy consumption plays a dominant role in climate change and many other pollutant emissions (such as SO<sub>2</sub> and PM<sub>2.5</sub>). Compared with these pollutant emissions, energy intensity has a more direct relationship with economic activity. Energy intensity-

based environmental policy may help to balance economic growth and environmental protection. This point is very important in developing economies which are facing both issues. This also allows developed economies to sustain a sufficient level of consumption. Moreover, the spatial distribution dynamics of energy intensity are closely related to the diffusion of energy-related technologies. Convergence in energy intensity may imply the decline in technological difference across regions over time. Lack of convergence in energy intensity may suggest that national governments and international organizations should pay more attention to spatial knowledge diffusion to promote energy efficiency in high energy intensity countries.

China is a large country with extremely heterogeneous regions. Consequently, there are large differences in energy intensity across regions. With the persistent decline of energy intensity in China in recent years, there are already considerable works (such as Ma and Stern [14]; Zhao et al. [15]; Song and Zheng [16]; Wu [17]; Yu [18]; Li and

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Lin [19]; Huang et al. [20]) that focus on forecasting future energy consumption or searching for the determinants of energy intensity. To our best knowledge, few papers have focused on the spatial distribution dynamics of energy intensity in China. The only two works related to this issue are Herrerias and Liu [21], and Zhang and Broadstock [11]. Herrerias and Liu [21] examined the stochastic convergence of electricity intensity across Chinese provinces using a unit-root test approach, while Zhang and Broadstock [11] focus on the convergence clubs across Chinese provinces. A focus on the convergence of electricity can only provide a partial view of energy intensity. Moreover, since provinces are the largest regional administration units in China, the aggregated provincial data set may conceal the intra-provincial heterogeneity in terms of energy intensity. Finally, Chinese regions differ greatly in terms of economic and population size. For example, the economic and population size of Guangdong is approximately 77 and 34 times than that of Tibet in 2013. The size difference among Chinese prefectures is even larger. Ignorance of regional size may lead to the biased estimation of real performance in energy intensity across Chinese regions. In 2006, urban contribution makes up 84% of commercial energy consumption in China (Dhakal [22]). With the rapid urbanization in the past decade, this share has increased substantially for sure. However, to the best of our knowledge, there is no studies focus on the evolution behaviour of energy intensity across Chinese cities.

This paper attempts to shed light on the dynamic behaviour of energy intensity in Chinese cities. This paper contributed to the existing literature in several ways. First, this study examines energy intensity in 286 Chinese prefectural-and-above (PAA) level cities while the existing energy intensity related studies are mainly based on provincial panel data. The panel dataset of 286 PAA level cities provides us with sufficient observations and more information in our nonparametric analysis than a provincial one. In addition, China is in the process of rapid urbanization. Thus, the examination of the behaviour of energy intensity in cities may help establish a sustainable urban system. Second, this paper developed a new weighted distribution dynamics approach which can take into account of city size. It is different from the conventional convergence analysis methods as it can provide more comprehensive information on the spatial dynamic behaviour of the entire shape of energy intensity distribution, particularly for intra-distribution mobility and the formation of convergence clubs. Considering size heterogeneity exists in most economic samples, this weighted distribution dynamics approach can be applied in a broader context in the future. Third, in order to explain the spatial distribution dynamics of energy intensity in Chinese cities, this paper also tries to identify possible determinants of the observed distribution dynamics through the analysis of conditional distribution dynamics, which is new in this field. Differing from the arbitrary division of regional or income convergence clubs, this conditional distribution dynamics approach provides new insight in the formation of convergence clubs. Finally, China is one of the few country that experienced high speed economic growth and significant decline in energy intensity. Examination on China's successful practice in the past decade may provide experience for other developing countries.

The remainder of this paper is arranged as follows. In Section 2, a brief review of the related literature is provided. Section 3 explains the methodology of this paper. The data construction is introduced in Section 4. Section 5 presents the empirical analyses. Conclusions and discussions are presented in Section 6.

## 2. Review of related literature

The concept of convergence is drawn from the literature on economic growth. With increasing environmental awareness, convergence and distribution dynamics analyses have been employed to investigate the evolution trend of energy intensity. The empirical literature can be broadly grouped into three strands. The first strand of the literature examines sigma-convergence or the dispersion of the distribution of

energy intensity over time. Sun [23] used mean deviation to measure the level of difference in energy intensity among OECD countries for the period 1971–1998. He showed that the level of difference in energy intensity declined in the sample period. Liddle [5] analysed the convergence of electricity intensity across a sample of IEA countries for the period 1960–2006. He found significant evidence of sigma-convergence for electricity intensity. However, the results also show that the electricity intensity convergence is less dramatic than energy intensity convergence. With a larger data set, Liddle [7] provided more evidence of sigma-convergence of energy intensity. The author also showed that the convergence patterns differed greatly among geographical country groups. Since  $\sigma$ -convergence provides much less information for the dynamics of energy intensity, the popular practice is to combine  $\sigma$ -convergence analysis with other approaches to obtain more robust results. Examples include Ezcurra [4], Maza and Villaverde [24], Duro [25] and Mulder et al. [10].

The second strand of the literature uses conventional parametric approaches to examine the existence of absolute, conditional, or stochastic convergence. Markandya et al. [3] investigated the  $\beta$ -convergence of energy intensity among 12 transition economies and EU15 members. Their results support the existence of conditional  $\beta$ -convergence across these countries. Their findings also show that the predicted values of energy intensity for the 12 transition countries significantly converge to the EU level. Le Pen and Sévi [6] examined the stochastic convergence of energy intensity across 97 countries in the period 1972–2003. Their results do not support the existence of global convergence in energy intensity. Instead of energy intensity, Mohammadi and Ram [26] examined  $\sigma$ -convergence and  $\beta$ -convergence of energy and electricity per capita across countries for the period 1971–2007. They found weak evidence of energy consumption convergence, and strong evidence of electricity convergence. Meng et al. [27] examined stochastic convergence of energy use per capita across 25 OECD countries over the period 1960–2010. Their results support the presence of stochastic convergence in energy use in OECD countries. Kiran [9] used a fractional integration approach to test the convergence of energy intensity for 21 OECD countries over the period 1980–2010. However, the author only observed convergence in nine countries. Fallahi [28] found the existence of convergence and persistence in energy per capita among 109 countries for the period 1971–2013. Some studies focused on convergence in energy across US states. Burnett and Madariaga [12] examined the convergence in energy intensity across US states. The above studies imply that the results of  $\beta$ -convergence are quite mixed. This may be due to the use of different samples and different econometric approaches. In addition, these traditional convergence analyses are based on models for 'representative' economies. These studies contribute to the understanding of the evolution of CO<sub>2</sub> emissions in general, but provide little information on spatial distribution dynamics. For example, traditional convergence approaches can verify the existence of convergence clubs, but give no information about the formation and evolution of convergence clubs.

The third strand of the literature utilises distribution dynamics approaches to examine the dynamic behaviour of energy intensity. Ezcurra [4], using a non-parametric stochastic kernel approach, examined the spatial distribution of energy intensity in 98 countries during the period 1971–2001. The results verified the existence of convergence in energy intensity over the sample period. Maza and Villaverde [24] combined  $\sigma$ -convergence,  $\beta$ -convergence, and a non-parametric distribution dynamics approach to explore differences in per capita electricity use across 98 countries over the period 1980–2007. Their results revealed a weak convergence process in per capita electricity over the sample period. They also found that the reduction in disparity related to three factors, namely the rapid economic growth in some developing countries, energy saving measures in most developed countries, and the growing awareness of energy issues in rich countries. Herrerias [8] used a weighted distribution dynamics approach to examine energy intensity convergence across 83 countries for the period

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