Energy Policy 121 (2018) 300–313

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

From club convergence of per capita industrial pollutant emissions to industrial transfer effects: An empirical study across 285 cities in China

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ARTICLE INFO

Keywords:
Club convergence
SO_2 emissions
Soot emissions
Logit model
Industrial transfer

ABSTRACT

The process of industrialization has led to an increase in air pollutant emissions in China. At the regional level, industrial restructuring and industrial transfer from eastern China to western China have caused a significant difference in pollutant emissions among various cities. This paper analyzes per capita industrial pollutant emissions across 285 prefecture-level cities from 2003 to 2015, aiming to reveal how industrial transfer affects the formation of convergence clubs. Whether industrial pollutant emissions across heterogeneous cities converge to a unique steady-state equilibrium is first identified based on the concept of club convergence. Logit regression analysis is then applied to assess the effects of industrial transfer on the observed clubs. The log *t*-test highlights four convergence clubs for industrial SO_2 emissions and three clubs for industrial soot emissions. The regression analysis results reveal that the effects of industrial transfer can lead to multiple steady-state equilibria, suggesting region-specific environmental policies and execution strategies. In addition, accelerating the development of clean energy technologies in emission-intense regions should be further emphasized.

1. Introduction

With rapid industrialization, air pollution in China is becoming a major concern of the global community. Due to the limitation of resource endowments, 70% of the energy consumed in China comes from coal. The combustion of fossil fuel such as coal and oil has produced a large number of air pollutants, including sulfur dioxide (SO_2) and soot (Bi et al., 2014). SO_2 emissions in China have surpassed the sum of the members of the Organization for Economic Cooperation and Development (OECD) and the USA.[1] These pollutant emissions can severely harm human health and the ecosystem, especially in some metropolitan areas (Zhang et al., 2017). Sulfate stemming from SO_2 is an essential component in the formation of PM2.5 (Pui et al., 2014), which has contributed to the haze in many cities.

Due to differences in industrial structures, pollutant emissions display considerable heterogeneity among regions. Notably, industrial upgrading has profoundly influenced the evolution paths of air pollutant emissions. With the in-depth restructuring of the division in the international industry and domestic industry since the Asian financial crisis in 1997, the central and western regions have been receiving considerable industrial transfer from the global market and eastern China. On the one hand, the central and western regions have the comparative advantages of abundant energy resources and low labor costs to attract investments in high-energy consumption industries. The development campaign in the western regions since 2000 has further promoted the industrial shift. On the other hand, the environmental standards and the market accession of some industries in the central and western regions are relatively low. It is estimated that SO_2 emissions in the western regions increased 10% more than those in the eastern regions between 1990 and 2005. Consequently, industrial transfer presents a new perspective for examining the evolution patterns of air pollutant emissions.

The Chinese government has adopted several measures to control air pollution since the late 1980s. In 1989, the State Environmental Protection Administration started to carry out the quantitative evaluation mechanism on the comprehensive renovation of the urban environment at the city level, examining 113 important environmental conservation cities. In 1995, a duo-control-zone scheme including an SO_2-control zone and an acid-control zone was proposed in the Atmospheric Pollution Prevention and Control Law. During the 10th and 11th Five-Year Plan, the Total Emission Control strategy was used to establish a nationwide SO_2 emissions reduction target allocated to local governments. In addition, several technology-based regulations such as installing flue-gas desulfurization equipment (FGD) were also

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[1] OECD Economic Surveys: China 2013. OECD publishing. http://dx.doi.org/10.1787/eco-surveys-chn-2013-en.

https://doi.org/10.1016/j.enpol.2018.06.039
Received 5 February 2018; Received in revised form 25 June 2018; Accepted 26 June 2018

used to control air pollutant emissions (Shin, 2013). Nevertheless, the effects of such environmental policies may be limited and uncertain if the cross-sectional heterogeneity of pollutant emissions are ignored (Kanada et al., 2013).

Pollution convergence can be used to measure the transition paths of pollutant emissions among regions. Due to the considerable disparity in pollutant emissions across regions, the following two research questions are worthy of study: 1) Are the pollutant emissions among regions in China converging to a common steady-state level or multiple steady-state levels? 2) Which factors affect the evolution behaviors of regional pollutant emissions and transitional heterogeneity? Understanding the convergence patterns of pollutant emissions and the determinants of convergence clusters is crucial for policymakers aiming to establish appropriate environmental policies.

Although several existing studies have focused on the analysis of CO_2 emissions convergence in China (Huang and Meng, 2013; Wang and Zhang, 2014; Wang et al., 2014; Wu et al., 2016), the literature on the convergence patterns of SO_2 and soot emissions is quite limited. He et al. (2012) examined the effect of China's economic transition on SO_2 and soot emission intensity across 287 cities, but their study did not discuss the convergence behavior of pollutant emissions. Hao et al. (2015) studied the absolute and conditional β-convergence of SO_2 emissions, but their study considered only 113 important environmental conservation cities in China and left many high air pollution cities undiscussed. Although industrial transfer may affect the growth path of pollutant emissions in an economic transition country, none of the aforementioned studies evaluated the effects of industrial transfer.

This paper aims to examine the effects of industrial transfer on pollutant emissions convergence patterns in China. Two types of pollutant emissions, SO_2 and soot emissions, will be discussed. A two-step analysis is conducted by combining the club convergence test with logit regression analysis. First, the log *t*-test methodology (Phillips and Sul, 2007) is used to examine the convergence behavior of per capita industrial SO_2 and soot emissions across 285 cities from 2003 to 2015. The log *t*-test can identify convergence clubs endogenously but cannot determine which factors induce the formation of convergence clusters because the method focuses only on SO_2 and soot emissions data and leaves many factors unexplored. Furthermore, by applying logit regression analysis, the effects of industrial transfer on the formation of the observed convergence clusters can be assessed.

This paper contributes to the literature in two ways. First, the effects of China's industrial transfer on the convergence patterns of air pollutant emissions are analyzed. Second, the analysis is carried out based on a comprehensive dataset, including 13 years (2003–2015) of data from 285 prefecture-level cities on two pollutants. By applying the club convergence methodology, the heterogeneity and transition dynamics of the pollutant emissions of Chinese cities are investigated.

The rest of the paper is organized as follows. Section 2 examines the recent literature. Section 3 describes the methodology. Section 4 introduces the data. Section 5 presents the empirical study and analyzes the results. Section 6 provides the concluding remarks and policy implications.

2. Literature review

Applying the concept of convergence to economic growth studies originated from Barro and Sala-I-Martin (1992). The convergence hypothesis implies that poorer countries will catch up with the wealthier countries, while an equilibrium state for income level can be reached in the long term (Islam, 2003). Theoretically, the neoclassical growth model provides a fundamental basis for the income convergence hypothesis (Solow, 1956). Empirically, there are several notions of convergence and related methodologies, such as β-convergence, σ-convergence, stochastic convergence and club convergence.

β-convergence indicates a negative relationship between income growth rate and initial output (Mankiw et al., 1992). A cross-section regression methodology is typically employed to test β-convergence. According to Quah (1993), a negative coefficient cannot be used to conclude convergence because it represents only a necessary but not sufficient condition of convergence. Instead, nonparametric methods are suggested for testing convergence. σ-convergence measures the intra-distributional dynamics of income data and tests whether the dispersion of income among countries declines over time. When considering the time series properties of data, stochastic convergence is introduced, indicating the temporary effects of an exogenous shock to relative income (Carlino and Mills, 1993). The unit root analysis is typically used to test stochastic convergence.

When the heterogeneity of individuals is taken into consideration, many studies have revealed club convergence. Durlauf and Johnson (1995) identified convergence clubs in countries with different production functions via regression tree analysis. Quah (1997) found twin peaks in the cross-country patterns of economic growth, implying countries that draw level with one another only within convergence clubs instead of through simple patterns of convergence or divergence. Phillips and Sul (2007) proposed the log *t*-test based on the nonlinear time-varying factor model to examine convergence clubs endogenously. The methodology can identify temporal trend and spatial differences and allows the endogenous determination of convergence clubs.

Since the seminal paper by Strazicich and List (2003), the convergence hypothesis of pollutant emissions has received considerable attention in the recent environmental policy literature. Some studies have provided theoretical frameworks for emissions convergence. By combining income convergence and the Environmental Kuznets Curve (EKC), Bulte et al. (2007) found pollution emissions converging or diverging depending on regional income differences. A local government may race to the bottom and relax environmental regulations, which leads to a distorted pollution path and divergence in emissions. Brock and Taylor (2010) developed the Green Solow model to predict pollution convergence considering technological progress in abatement. According to the model, pollution emissions will increase when the impact of economic growth surpasses that of emission reduction technology and will decrease when the effect of economic growth is weaker than that of technological progress. Ordás Criado et al. (2011) developed a pollution growth model that deals with interactions among pollution, cleaning technology, and abatement costs. These authors suggested a dynamic abatement growth path in which the emissions growth rate is negatively related to the initial emissions level (a.k.a. defensive effect) and positively related to income growth (a.k.a. scale effect).

Another branch of the literature empirically tests the existence of emissions convergence across countries or regions. Evidence of convergence has been found in many research studies on per capita SO_2 and NO_x emissions. List (1999) applied the unit root test to examine the stochastic convergence of per capita SO_2 and NO_x emissions across 10 EPA regions in the U.S. during the 1929–1994 period and found evidence of conditional convergence. Lee and List (2004) examined the stochastic characteristics of NO_x emissions in the U.S. from 1900 to 1994 by using unit root tests and intervention analysis methods. The results suggested the convergence of NO_x emissions. Bulte et al. (2007) explored the temporal and spatial nature of SO_2 and NO_x emissions from 48 U.S. states from 1929 to 1999 by applying unit root tests and cross-section regression methods. The results implied stronger pollutant convergence after the implementation of the Clean Air Act Amendments of 1970 than during the period of local government control before 1970. By employing the Residual Augmented Least Squares-Lagrange Multiplier (RALS-LM) unit root test with structural breaks, Payne et al. (2014) explored the convergence of per capita SO_2 emissions among U.S. states and found evidence of stochastic convergence. Nourry (2009) analyzed per capita SO_2 emissions convergence by applying a pairwise comparison across 81 developed and developing countries over the period from 1950 to 1990. The results did not support the stochastic convergence of SO_2 emissions.