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How industrialization and urbanization process impacts on CO_2 emissions in China: Evidence from nonparametric additive regression models

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ABSTRACT

This paper examines the impacts of industrialization and urbanization on CO_2 emissions in China using nonparametric additive regression models and provincial panel data from 1990 to 2011. The empirical results show that there is an inverted U-shaped nonlinear relationship between industrialization and CO_2 emissions in the three regions in China. Urbanization follows an inverted U-shaped pattern with CO_2 emissions in the eastern region, and a positive U-shaped pattern in the central region. However, the nonlinear impact of urbanization on CO_2 emissions is insignificant in the western region. As a result, the differential dynamic effects of industrialization and urbanization on CO_2 emissions in the three regions should be taken into consideration in reducing China's CO_2 emissions.
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1. Introduction

As the largest developing nation in the world, China is currently in the process of industrialization and urbanization (Jiang and Lin, 2012). The industrialization level (i.e., industry sector value added/GDP) increased from 36.1% in 1990 to 41.3% in 2011, an average annual growth of about 1%. Over the same period, China's urbanization level rose from 26.4% to 51.3%, and it will increase to 60% and reach 880 million (UN projection) or 1 billion (MGI estimate) in 2030 (Dhakal, 2009). The rapid industrialization and urbanization have created huge challenges for the environment, especially in terms of energy consumption and CO_2 emissions. In 2012, China's total energy consumption reached 3.62 billion tons of standard coal while the total CO_2 emission was approximately 10 billion tons (Frieler et al., 2013). China has become the world's largest energy consumer and CO_2 emitter (Chen and Santos-Pauline, 2013).

Given that rapid industrialization and urbanization lead to a surge in China's CO_2 emissions, many scholars have conducted extensive studies on the effects of industrialization and urbanization on CO_2 emissions from a national perspective without consideration for regional differences (Hu et al., 2006; Jiang and Lin, 2012; Lin and Xie, 2014; Zhu et al., 2012). China has a vast territory, with apparent regional differences in resource endowments, level of economic development and population distribution (Du et al., 2012; Zhang and Nian, 2013). Meanwhile, the patterns of industrialization and urbanization also vary in the different regions (Wei et al., 2012; Zhang and Lin, 2012). Thus, CO_2 emissions are impacted by regional features whether at the overall or per capita level. The researches investigating the impacts of industrialization or urbanization on CO_2 emissions from only a national point of view ignore the effects of regional differences, leading to biased estimation. Considering this issue, we conduct a regional analysis of CO_2 emissions during the industrialization and urbanization process in China using provincial panel data. This study would be beneficial

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for industry regulation, urban planning and emission reduction policies in China.

The paper is concerned with the impacts of industrialization and urbanization on CO_2 emissions in China at the aggregate and regional levels. Using a panel data set covering 30 provinces over the period 1990–2011, we employ nonparametric additive regression models to explore the effects of industrialization and urbanization on CO_2 emissions in China while considering regional differences.

The remainder of the paper is as follows: Section 2 briefly reviews related literature and previous studies on the influences of industrialization and urbanization on CO_2 emissions. Section 3 describes the econometric method and sample data. Section 4 presents the empirical results. The conclusions and discussions are presented in Section 5.

2. Literature review

In recent decades, the effects of industrialization on CO_2 emissions have been extensively investigated at the overall industry or specific sectors level. Some studies concentrated on the relationships at the overall industry level without consideration for different industrial sub-sectors, and found that there was a positive link between industrialization and CO_2 emissions (Garcia and Von Sperling, 2010; Shahbaz et al., 2014; Shahbaza and Lean, 2012). Further analyses took this issue into account, and investigated different industrial sectors across different countries. For instance, Akbostanci et al. (2011) found that the manufacturing industry determined the changes in CO_2 emissions in Turkey. Similar results were found in Asia-Pacific and North American countries' electricity generation sectors by Shrestha et al. (2009); in four Latin-American countries' electricity generation sector by Ruiz-Mendoza and Sheinbaum-Pardo (2010); in European cement industry by Pardo et al. (2011); in Mexican manufacturing industries by Sheinbaum-Pardo et al. (2012) and Gonzalez and Martinez (2012); and in the EU27 iron and steel industry by Moya and Pardo (2013). However, some studies suggested that the link between industrialization and CO_2 emissions was not linear. For example, using the ARDL model, Shahbaz et al. (2014) analyzed the impact of industrialization on CO_2 emissions in Bangladesh from 1975 to 2010, and found that EKC existed between industrial development and CO_2 emissions.

In addition to industrialization, urbanization has also been of increased research interest in the modeling of regional urban emissions (Gurney et al., 2009). A large number of studies are concerned with the nexus between urbanization and CO_2 emissions at the national and city levels. Most studies focus on the relationships at the national level without consideration for the different stages of development, and they found that there is a positive link between urbanization and CO_2 emissions (York, 2007; Sadorsky, 2014). Further studies considered this issue and explored the impacts of different stages of development on CO_2 emissions (Ehrhardt-Martinez et al., 2002; Martinez-Zarzoso and Maruotti, 2011). Poumanyvong and Kaneko (2010) insisted that the nexus between urbanization and CO_2 emissions in all countries were not homogenous; and a positive link exists for all income groups, and most prominent in the middle-income group. However, using the semi-parametric panel data model, Zhu et al. (2012) analyzed the impact of urbanization on CO_2 emissions in 20 emerging countries over the period 1992–2008 and found that a nonlinear relationship exists between urbanization and CO_2 emissions rather than an inverted-U pattern. Some studies have also examined these issues at the city level. Fragkias et al. (2013) showed that larger cities are not more emissions-efficient than smaller ones due to the fact that larger cities aren't more energy-efficient than smaller ones. However, Barla et al. (2011) and Liu and Sweeney (2012) reached the opposite conclusions that the compact city scenario is likely to reduce the energy consumption and CO_2 emissions per household compared to the dispersed city scenario.

With accelerated industrialization and urbanization and the increasing pressures to conserve energy and reduce emissions in China, research on this subject is gaining wide attention. From the perspective of the overall industry, Li and Xia (2013) and Zhou et al. (2013a) concluded that industrialization was one of the most important factors affecting China's CO_2 emissions. These are attributable to low energy efficiency, heavy industrialization and absence of environmental awareness. In addition, more research studied the relationship between industrialization and CO_2 emissions from a specific industrial sector perspective (Ke et al., 2012; Sun et al., 2011; Xu et al., 2012a), and found a positive link. Given that the proportion of heavy industry in total industry increases from 71.52% in 2004 to 77.12% in 2012, and the slow development of energy-saving technology in recent years (Jiang and Lin, 2012), it is inevitable that the heavy industries (e.g., iron and steel, cement, power industry) will increasingly determine China's CO_2 emissions. But Wen et al. (2014) showed that the development of the iron and steel industry increases CO_2 emissions in the short term, and reduces CO_2 emissions in the long term due to energy-saving technology improvements.

Parallel to studies on the link between industrialization and CO_2 emissions, there have been a large number of studies related to the correlation between China's urbanization and CO_2 emissions. By studying the influencing factors of CO_2 emissions, some studies found positive links between urbanization and CO_2 emissions at the national level (Sadorsky, 2013; Zhang et al., 2011a,b). This is mainly attributed to the rapid growth of private transport, large-scale construction of public infrastructure (e.g., road networks, sanitation and drainage systems) and steel and cement production caused by urban construction (Zhang and Lin, 2012). Furthermore, Fan and Xia (2012) demonstrated that urbanization had a long run and positive causal relationship with CO_2 emissions in China. Some empirical results were also obtained at the city level in China (Hua et al., 2012; Fang et al., 2013). Since the rapid urban expansion and spatial characteristics of soil organic carbon, urbanization has boosted CO_2 emissions in Shanghai in China (Xu et al., 2012b). However, the opposite effect emerged in Xiamen city, where a large area of vegetation in the suburban and exurban areas was beneficial to CO_2 emission reductions (Ren et al., 2011).

Though the impacts of industrialization and urbanization in China have been discussed extensively, there are two main shortcomings. First, ignoring regional heterogeneity in CO_2 emissions and its driving factors, the vast majority of existing literature studies the effects of industrialization and urbanization on CO_2 emissions at the national level, and only a few empirical works were done at the regional or inter-provincial level (Feng et al., 2012; Li et al., 2012; Wang et al., 2011c). Second, most of these studies only use linear models to analyze the influences of industrialization or urbanization on CO_2 emissions. Nonlinear relationships embodied in economic variables are largely ignored.

This study is different from previous researches in two aspects. The first is that this study examines the impacts of industrialization and urbanization on CO_2 emissions from a regional perspective in order to gain insights into the regional differences. The second is that we investigate the linear and nonlinear effects of industrialization and urbanization on CO_2 emissions using nonparametric additive regression models since it can capture the linear and nonlinear relationships between economic variables.

3. Methodology and data

3.1. Nonparametric additive regression models

It is known that economic data being collected by many government and social science organizations have more complex design characteristics. It is difficult to acquire any prior model information in order to address various hypotheses. In this perspective, a pre-

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