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Environmental Kuznets curve for $PM_{2.5}$ emissions in Beijing, China: What role can natural gas consumption play?

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ABSTRACT

Beijing has been the fastest-growing megacity in China, however it faced severe air pollution in recent years, particularly the notorious fine particulate matter ($PM_{2.5}$). In response, Beijing increased the use of natural gas since 2008; therefore, natural gas consumption (NGC) soared rapidly, accounting for over 30% of total energy need in 2016. This study explores the long- and short-run effects of NGC on $PM_{2.5}$ emissions within the framework of the environmental Kuznets curve (EKC) in Beijing by employing the autoregressive distributed lag (ARDL) approach. To do this, the long-term and monthly $PM_{2.5}$ data based on ground monitoring are used for the period of April 2008 through December 2016 (2008 M04-2016 M12). The empirical results suggest, in the long run, an inverted U-shaped EKC link exists between $PM_{2.5}$ emissions and per capita gross domestic product (GDP); with 16,973 yuan for per capita monthly GDP, the EKC will reach its peak. Although the NGC in Beijing can mitigate $PM_{2.5}$ emissions in both the long run and short run, its mitigation effect would be weakened over time. Furthermore, increasing vehicle quantity would lead to higher concentrations of $PM_{2.5}$, whereas the proportion of tertiary industry exerts a negative effect on $PM_{2.5}$ in Beijing. At the end of the article, several key policy implications are highlighted both for mitigating $PM_{2.5}$ and for promoting growth in natural gas industry in Beijing.

1. Introduction

As the national center of economics, politics, and culture, Beijing has developed rapidly and, therefore, become the fastest-growing megacity in China. However, meanwhile Beijing has also faced severe air pollution, particularly the unprecedentedly high levels of $PM_{2.5}$ (i.e., particulate matter smaller than 2.5 μg) (Dong and Zeng, 2018; Meng et al., 2016). Since the spring of 2012, severely hazardous haze and fog have swept across Beijing and become a disastrous weather phenomenon (Liu et al., 2014; Ma et al., 2016). In 2016, the annual average $PM_{2.5}$ concentrations in Beijing were observed at about 73 μg/m^3, greatly exceeding the World Health Organization (WHO) guideline value of 10 μg/m^3 (WHO, 2005). In response, the Beijing's government takes natural gas as an effective alternative to other fossil fuels (e.g., coal, petroleum) as the combustion of coal and petroleum contributes most of air pollutants (Dong et al., 2018), and has introduced a series of policies to promote the development of natural gas consumption (NGC) (Dong et al., 2017a). Accordingly, NGC in Beijing has soared from 60.7×10^8 m^3 in 2008 to 160.3×10^8 m^3 in 2016 (Fig. 1) since 2008 (Beijing Olympic Games held in August 2008), with an average annual growth rate of 11.4%. Meanwhile, the energy structure in Beijing has changed significantly with the rapidly increasing NGC; the share of natural gas obtained the most significant growth, rising from about 13% in 2008 to over 30% in 2016 (BMBS, 2017). Furthermore, according to

Abbreviations: ADF, Augmented Dickey Fuller; AIC, Akaike information criterion; APEC, Asia-Pacific Economic Cooperation; ARDL, autoregressive distributed lag; BGGRI, Beijing Gas Group Research Institute; BMBS, Beijing Municipal Bureau of Statistics; BMCDR, Beijing Municipal Commission of Development and Reform; CO_2, carbon dioxide; CUSUM, cumulative sum; CUSUMSQ, cumulative sum of squares; ECM, error correction model; ECT, error correction term; EKC, environmental Kuznets curve; FDI, foreign direct investment; FYP, Five-Year Plan; GDP, gross domestic product; GHG, greenhouse gas; IS, industrial structure; IVA, industrial value added; MCAQMP, Mission China air quality monitoring program; Mtce, million ton coal equivalent; NGC, natural gas consumption; NO_2, nitrogen dioxide; OLS, ordinary least squares; $PM_{2.5}$, particulate matter smaller than 2.5 μg; PP, Philips-Perron; SEM, spatial error model; SLM, spatial lag model; SLM U, Sasabuchi-Lind-Mehlum U; SO_2, sulfur dioxide; V, vehicle quantity; WHO, World Health Organization

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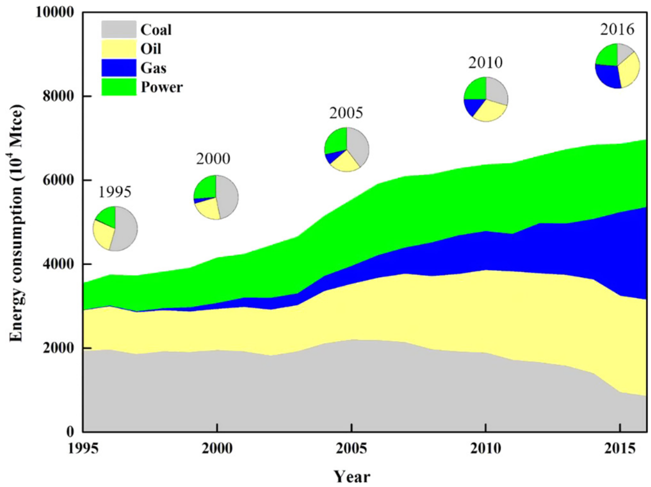

Fig. 1. Total energy consumption and structure from 1995 to 2016 in Beijing. ***Data source:*** BMBS (2017).

the plan from Beijing's government, the NGC will reach 200 × 10^8 m^3 by 2020, accounting for 33% of the total energy needs.

Given the above background, it is critical to investigate the dynamic relationship between NGC and $PM_{2.5}$ emissions in Beijing, which is particularly useful not only for combating $PM_{2.5}$ emissions, but also for promoting growth in Beijing's natural gas industry. However, to the best of our knowledge, very few studies deal with the dynamic causal relationship between NGC and $PM_{2.5}$ emissions in the context of Beijing. In addition, the short-term and yearly $PM_{2.5}$ data from ground monitoring stations or long-term and yearly $PM_{2.5}$ data from satellite monitoring stations usually adopted in existing studies ignore the seasonal differences in the level of $PM_{2.5}$ emission, which may lead to errors in estimation and analysis. Most importantly, the environmental Kuznets curve (EKC), which was first stated by Kuznets (1955), has been widely used for over 60 years as a means of analyzing the energy-growth-pollutant nexus. Research on the energy-growth-pollutant nexus within the framework of EKC is critical for stakeholders and policymakers to draft appropriate policies for mitigating pollutions, particularly for developing countries which are currently striving to boost their economy (Sugiawan and Managi, 2016). However, based on the review of the literature to date, large numbers of researchers have investigated the determinants of $PM_{2.5}$ emissions from either physical and chemical perspectives, very few studies are done to investigate the socioeconomic drivers of $PM_{2.5}$ emissions within the framework of EKC, especially for Beijing, China. Given the above motivations, this study aims to investigate the dynamic causal relationship between NGC and $PM_{2.5}$ emissions in the context of Beijing by examining the validity of the EKC hypothesis and analyzing the effectiveness of NGC, based on the long-term and monthly data from April 2008 to December 2016 (2008M04-2016M12).

In relation to previous research, this study has three main contributions. First, different from the widely used short-term and yearly $PM_{2.5}$ data from ground monitoring stations or long-term and yearly $PM_{2.5}$ data from satellite monitoring stations, the long-term and monthly $PM_{2.5}$ data based on ground monitoring used in this study, which can reflect the seasonal differences in the level of $PM_{2.5}$ emission, can accurately analyze the socioeconomic drivers of $PM_{2.5}$. Second, besides some important indicator-including economic, social and meteorological dimensions, this study assumes NGC as a socioeconomic driver of $PM_{2.5}$ emissions; this could not only offer new evidence for developing specific policy to tackle $PM_{2.5}$ pollution, but also extend the common EKC model by adding NGC as a new explanatory variable. Third, to the best of our knowledge, this study is the first to take the case of Beijing as an example to explore the long- and short-run relationship between NGC and $PM_{2.5}$ emissions. This empirical analysis of this study is particularly useful for Beijing's government not only in devising long- and short-run plans for controlling $PM_{2.5}$ emissions, but also in promoting rapid development of the natural gas industry.

The remainder of this study is organized as follows. Section 2 reviews the related literature on the EKC and drivers of $PM_{2.5}$ emissions. Section 3 provides an overview of $PM_{2.5}$ emissions in Beijing. Section 4 introduces the data and methodology used. This study reports the results and discuss their implications in Section 5. Finally, Section 6 concludes the study and presents policy implications.

2. Literature review

2.1. Air pollution, economic growth, and the EKC

Since the EKC hypothesis was introduced by Kuznets in 1955, it has contributed to investigate the relationship between economic development and environmental pollutants. The EKC hypothesis posits that the relationship between economic growth and the level of environmental degradation follows an inverted U-shaped curve. In other words, the per capita income reduces the environmental quality during the early stage of economic growth, but after exceeding a certain level of per capita gross domestic product (GDP), the environmental quality improves with increasing economic growth. Investigating EKC hypothesis is useful for the research on energy-growth-pollutant nexus, thus a number of studies have been conducted to examine the hypothesis for various air pollutants at the country-specific level, regional level, and global level (Dong et al., 2017a). For example, Narayan and Narayan (2010) examine the EKC link between carbon dioxide (CO_2) emissions and economic growth for 43 developing countries. Similar empirical studies of the EKC for CO_2 emissions have been conducted by many scholars, such as Jalil and Feridun (2011), Jayanthakumaran et al. (2012), Yin et al. (2015), Alam et al. (2016), Cheng et al. (2017a), and Dong et al. (2017c). In addition to the EKC for CO_2 emissions, a number of researchers have tested the EKC hypothesis for other air pollutants, such as Leitao (2010), Cheng (2016) and Xu (2018) for sulfur dioxide (SO_2) emissions, Olale et al. (2018) for greenhouse gas (GHG) emissions, and Sinha and Bhattacharya (2016) for nitrogen dioxide (NO_2) emissions.

The preceding studies have explored the EKC link between various air pollutants and economic growth. However, based on the literature surveyed and to the best of our knowledge, very few studies have examined the EKC relationship between $PM_{2.5}$ emissions and economic growth. For instance, Ma et al. (2016) point out that the relationship between $PM_{2.5}$ and economic development in China is consistent with the EKC hypothesis. Likewise, the existence of an inverted U-shaped link between $PM_{2.5}$ emissions and economic development level is also confirmed by Xu et al. (2016), Cheng et al. (2017b), and Wang et al. (2017). However, there seems to be no empirical studies that have attempted to investigate the EKC relationship between $PM_{2.5}$ emissions and economic growth for Beijing. Most importantly, to the best of our knowledge, no empirical research has extended the common EKC model by adding NGC as a new explanatory variable.

2.2. Socioeconomic drivers of $PM_{2.5}$ emissions

Given the fact that the reduction of $PM_{2.5}$ emissions relies on the identification of the pollution source, large numbers of researchers have investigated the determinants of $PM_{2.5}$ emissions in recent years. However, due to the lack of sustained and spatially comprehensive data for $PM_{2.5}$ pollutants (Wang et al., 2017), many existing research on $PM_{2.5}$ emissions focus on exploring the source and formation of $PM_{2.5}$ by decomposing $PM_{2.5}$ from the physical and chemical perspectives (Guo et al., 2014; Wang et al., 2013). The formation of fog and haze is not only related to physical and chemical factors but also socioeconomic drivers. Therefore, it is important to clearly understand the socioeconomic drivers of $PM_{2.5}$ emissions when exploring emission