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What causes PM2.5 pollution? Cross-economy empirical analysis from socioeconomic perspective

Xi Ji[a,*], Yixin Yao[b], Xianling Long[c]

[a] School of Economics, Peking University, Beijing 100871, PR China
[b] Centro de Estudios Monetarios y Financieros (CEMFI), Madrid 28014, Spain
[c] Management Science and Engineering, Stanford University, Stanford 94305, USA

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ABSTRACT

Is it true that, as the mainstream intuition asserts, urbanization and industrialization are the two main socioeconomic drivers of PM2.5? How do the two trends affect PM2.5 emission? This paper quantitatively analyzes the socioeconomic drivers of PM2.5 through assessment on Stochastic Impacts by Regression on Population, Affluence and Technology (STRIPAT), based on the panel data of 79 developing countries over 2001–2010. The average levels of PM2.5 pollution are calculated using remote sensing data, overcoming the difficulties that developing countries are in lack of PM2.5 monitors and that point data cannot reflect the overall level of PM2.5 pollution on a large scale. Squared terms of income and urbanization and their cross term are included in the regression models respectively to analyze the possible heterogeneous impacts on PM2.5 emissions in different development stages. The results show that income, urbanization and service sector have significant impact on PM2.5 pollution. Income has a positive effect on PM2.5 all the time but the effect decreases as the level of urbanization or income goes up. An inverted U relationship exists between urbanization and PM2.5, in which PM2.5 pollution positively correlates with a low level of income or urbanization but negatively at a high level. Policy recommendations from the perspective of macro-level social and economic regulation are provided for developing economies to reduce PM2.5 pollution.

1. Introduction

1.1. Background

According to a global-scale estimate, PM2.5[1] concentrations are high in densely populated areas that are undergoing fast urbanization and industrialization (Van et al., 2010). Throughout history, many severe air pollution events happened in urbanizing and industrializing areas, such as the 1930 Meuse Valley fog (Nemery et al., 2001), the Great Smog of 1952 (Davis, 2002), the Los Angeles photochemical smog (Parrish et al., 2011) and Yokkaichi asthma (Guo et al., 2008). Currently, assessment of data on various countries shows that the PM2.5 accumulation in developed countries with high level of urbanization and industrialization (such as United States and Western Europe) is close to the natural background accumulation,[2] while developing countries that are in the process of rapid urbanization and industrialization are suffering from severe air pollution and people there are exposed to high levels of particulate matter (WHO, 2006). For example, in January 2013, northern China experienced a prolonged smog, the PM2.5 peak shooting over 800 μg/m^3, 32 times higher than the World Health Organization (WHO)'s guideline value (Zhou et al., 2015). In June of the same year, Southeast Asia was hit by a severe haze and PM2.5 accumulations reached 329 μg/m^3 (Betha et al., 2014). Van et al. (2015) estimated that the percentage of global population living in areas where the PM2.5 concentrations were above the WHO guideline level (35 μg/m^3) increased from 22% in 1998–2000 to 30% in 2010–2012.

Given the fact that many developing countries suffer from PM2.5 pollution, it seems plausible that industrialization and urbanization are the main drivers of PM2.5 pollution, which is the mainstream view. However, this view lacks empirical tests and needs to be examined through quantitative analysis. Thus, this study investigates the socioeconomic driving forces of PM2.5 in developing countries, using the Stochastic Impacts by Regression on Population, Affluence and Technology model (STIRPAT), on a panel dataset of 79 developing countries over the period 2001–2010.

* Corresponding author.
E-mail address: jixi@pku.edu.cn (X. Ji).

[1] Fine particles with a diameter of 2.5 μm or less.

[2] The accumulation of a given species in a pristine air mass in which anthropogenic impurities of a relatively short lifetime are not present.

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1.2. Literature review

There is large body of literature studying socioeconomic driving forces of air pollution, but most of them focused on carbon dioxide, and others targeted sulfur oxides, oxides of nitrogen or PM10. As for PM2.5, there have been plentiful studies focusing on source apportionment, including both natural processes and human activities, from a micro-level perspective (Kaur et al., 2007; Belis et al., 2013; Pui et al., 2014; Karagulian et al., 2015; Li, Zhou, et al., 2015; Liang et al., 2016), while its socioeconomic driving forces were almost ignored. Only recently, few studies came to realize the importance of the macro drivers of PM2.5 pollution. Xu and Lin (2016) and Xu et al. (2016) analyzed the impact of income, energy intensity, urbanization, private vehicles and coal consumption on PM2.5 pollution with a panel dataset of 29 provinces in China over 2001–2012.

Population, income, technology and industrial structure were the four socioeconomic factors of air pollution that were widely studied in recent literature.

First, in many studies, the population factor is demonstrated by the population size and structure. Population size was related to carbon emissions in Cole and Neumayer (2004), to non-renewable energy consumption in Salim and Shafiei (2014). Population structure mainly refers to the level of urbanization, measured as the percentage of urban population in total population.[3] York (2007) analyzed a panel dataset of 14 European Union countries over 1960–2000 and found that urbanization had a positive, monotonic effect on energy consumption, which indicated increased pollution. A study by Liddle and Lung (2010) on a panel dataset of 17 developed countries covering the period 1960–2005, however, did not find significant impact of urbanization on carbon emission. Martínez-Zarzoso and Maruotti (2011) concluded that there was an inverted-U relationship between urbanization and carbon emission, using a panel dataset of 88 developing countries over the period 1975–2003. Xu and Lin (2015) found the nonlinear effect of urbanization on CO_2 emissions varies across regions in China: inverted U-shaped pattern in the eastern region, positive U-shaped pattern in the central region while insignificant nonlinear effect in the western region. Rafiq et al. (2016) showed that although urbanization is insignificant in impacting CO_2 emissions, it seems to be a major factor behind energy intensity.

Second, income, usually demonstrated as GDP per capita, is mostly regarded to have an inverted-U relationship with environmental pressure, known as Environmental Kuznets Curve (EKC). EKC is expressed as follows: at the early and lower stage of development, environmental pressure increases as income increases; however, when income reaches a threshold value, environmental stress decreases (Grossman and Krueger, 1996). The trade-off between consumption and good environment can explain the phenomena above: people spend most of their income on consumption when income is meagre, causing growing environmental pollution; but as income increases, the marginal utility of clean environment gradually grows and finally surpasses that of consumption (Ji and Chen, 2017). Thus, the willingness to pay for environmental protection rises as well and reduces pollution (Roca, 2003). However, some empirical studies did not support EKC and showed different impact of income on environment. For example, Kaika and Zervas (2013a) summarized 35 studies over 1992–2009 focusing on the impact of income level on carbon emission, and found various results, such as positive, inverted-U or no significant relationship at both national and global level. Baek (2015) examined the EKC hypothesis in the Arctic nations and provided little evidence of the existence of the hypothesis.

Third, energy intensity is widely used as a proxy for technology level. It is a common view that the impact of economic activities on environment is smaller when more energy efficient technologies are applied (Kaika and Zervas, 2013a). Using a panel dataset of 208 countries from year 1975 to 2000, Fan et al. (2006) found that the impact of energy intensity on carbon emission differed across developmental stages: at low income stage, energy intensity had significant effect on carbon emission, while at middle and high income stage, the effect was apparent yet weak. Sadorsky (2014) also found that energy intensity had significant effect on carbon emission, using a panel dataset of 16 emerging countries over year 1971–2009.

Fourth, industrial structure is often measured by the percentage of added value in GDP in different sectors: agriculture, industry and service. The impact of industrial structure on environment pressure is another possible explanation for EKC. At the early stage of development, industrial activities dominate, resulting in higher natural resources consumption and severer environmental degradation; later, as high-tech industry and service sector gradually replace energy intensive industry, the impact of economic activities on environmental pressure becomes smaller (Dinda, 2004). Martínez-Zarzoso and Maruotti (2011) found a weak impact of industrialization on carbon emission, using a panel dataset of 73 countries over 1973–2003. Li and Lin (2015) found that the impacts of industrialization on energy consumption and carbon emission varied with different income levels: in lower middle and high income groups, industrialization accompanied less energy consumption but more carbon emission, while in upper middle income groups no significant effects were found.

1.3. Research objectives

Though many studies have investigated and identified the main socioeconomic driving forces of some air pollutants like carbon dioxide and sulfur oxides, few have explored the socioeconomic drivers of PM2.5. In order to find a reasonable explanation for the severe PM2.5 pollution in developing countries to assist relevant policy design, it is urgent to quantitatively analyze the socioeconomic driving forces and macro mechanism. Since many developing countries lack ground-based monitoring PM2.5 data, this paper uses the global satellite observations of PM2.5 concentrations over 2001–2010, provided by Socioeconomic Data and Applications Center (SEDAC),[4] and socioeconomic data of 79 developing countries to analyze the driving forces and provide a quantitative basis for PM2.5 control.

The rest of this paper is organized as follows: Section 2 presents the data, empirical models and research methodology. Section 3 presents the empirical results. Section 4 discusses the results and Section 5 draws the conclusion.

2. Material and methods

2.1. Data

2.1.1. Data of the average PM2.5 concentrations

The average PM2.5 concentrations are calculated based on the global annual average PM2.5 grids over the period 2001–2010, provided by SEDAC (Battelle and Center, 2013; de Sherbinin et al., 2014), according to the boundaries of each country. The original raster grids from SEDAC have a grid cell resolution of $0.5^{\circ} \times 0.5^{\circ}$ and cells at different latitudes represent different actual sizes on Earth, which means the arithmetic average of the PM2.5 grids within the boundaries of a country is not the actual average PM2.5 concentrations of that country. To address such problem, the weighted average PM2.5 concentrations of each country are calculated. The formula is as follows,

[3] Some literature explores the relationship between age structure of population and environmental pressure.

[4] SEDAC, the Socioeconomic Data and Applications Center, is one of the Distributed Active Archive Centers (DAACs) in the Earth Observing System Data and Information System (EOSDIS) of the U.S. National Aeronautics and Space Administration.