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Impacts of Migration on Urban Environmental Pollutant Emissions in China: A Comparative Perspective

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Abstract: In recent years, researchers have devoted considerable attention to identifying the causes of urban environmental pollution. To determine whether migrant populations significantly affect urban environments, we examined the relationship between urban environmental pollutant emissions and migrant populations at the prefectural level using data obtained for 90 Chinese cities evidencing net in-migration. By dividing the permanent populations of these cities into natives and migrants in relation to the population structure, we constructed an improved Stochastic Impacts by Regression on Population, Affluence and Technology model (STIRPAT) that included not only environmental pollutant emission variables but also variables on the cities' attributes. We subsequently conducted detailed analyses of the results of the models to assess the impacts of natives and migrants on environmental pollutant emissions. The main findings of our study were as follows: 1) Migrant populations have significant impacts on environmental emissions both in terms of their size and concentration. Specifically, migrant populations have negative impacts on Air Quality Index (AQI) as well as $PM_{2.5}$ emissions and positive impacts on emissions of NO_2 and CO_2. 2) The impacts of migrant populations on urban environmental pollutant emissions were 8 to 30 times weaker than that of local populations. 3) Urban environmental pollutant emissions in different cities differ significantly according to variations in the industrial structures, public transportation facilities, and population densities.

Keywords: migration; urban; environmental pollutant emissions; Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model

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1 Introduction

In recent decades, urban populations throughout the world have been increasing at an annual rate of 0.5%, with the figure for the global urbanization level having reached 55%. It is projected that the number of people living in cities will increase to 6.5 billion by 2050, reflecting an increase of 2.5 billion urban residents (United Nations, 2017). As the largest developing country, China has experienced rapid urban population growth accompanied by extensive migration flows from the countryside to urban areas since the 1980s (Fang, 2018). Some researchers suggest that migrant populations have contributed to the growth of China's economy, accounting for 20%–30% of this growth (Ma and Zhang, 2004; Li and Yin, 2005; Zhang, 2015). However, migrant populations have also been linked to an acceleration of urban environmental problems in China. For example, in some cities, air pollution, water shortages and pollution, increasing waste, and low efficiency of land use are serious concerns. According to the *Report on the State of the Ecology and Environment in China*

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2017, air quality in 239 out of 338 cities is below the national standard, indicating that environmental issues affect almost 70% of China's cities. Moreover, the China National Plan of New Urbanization (2014–2020) projects that about 100 million people will migrate to urban areas, which will inevitably exert further pressure on urban resources and environments. Hence, a study on the relationship between migration and urban environments from the perspectives of current urban management regimes and future sustainable urban development would be salient.

Most existing studies have focused on the relationship between urbanization and the environment in China, given that the urbanization process is generally conceptualized as population movements from rural areas to urban areas, with the level of urbanization considered as a key indicator of social and economic development. Furthermore, most of these studies have focused on large-scale ecological and environmental issues, such as the urban heat island, land use, and diminishing water resources as well as on quantitative evaluations of the degrees of coupling and coordination between urbanization and ecological and environmental systems (Liu et al., 2005; Zhang et al., 2010; Fang and Wang, 2013; Li et al., 2014). In addition, in light of China's rapid urbanization and industrialization processes, which are characterized by accelerated energy consumption, recent studies have applied the STIRPAT model to examine CO_2 emissions (Poumanyvong and Kaneko, 2010; Li et al., 2011; Zhang and Lin, 2012; Liu et al., 2015). Although migration is the primary population-related process in China, empirical research focusing specifically on the environmental impacts of migration have been limited (Qin and Liao, 2016). Up to now, studies that have examined the environmental impacts of migration have only evaluated the environmental impacts of ecological migration and reservoir migration (Min et al., 2012; Liu and Wang, 2013).

Within developing countries, population movements are considered more important than natural increases in the population. Therefore, the relationship between migration and the environment, and especially global climate change, has emerged as a hot topic of research (Bongaarts, 1992; Hunter, 2000; Hogan, 2007; Bilsborrow and Henry, 2012; Harper, 2013; Neumann and Hilderink, 2015). Some researchers have suggested that migration contributes to several environmental problems relating, for example, to solid waste treatment, transportation, energy consumption, air and water pollution, and food consumption at local levels because of continuous increases in the population size and density (Bartlett and Lytwak, 1995; Garling, 1998; Hope and Lekorwe, 1999; Marshall, 2005). Other researchers have suggested that despite all of the negative environmental impacts of migration, increased concentration of the population within urban areas can lead to improvements in the economy of scale relating to public services, infrastructure, energy consumption, and environmental management that result in a reduction in the overall pressure exerted on the environment and on natural resources (Fang et al., 2008; Seto et al., 2010). Historically, there has been a heated and lengthy debate on the relationship between populations and the environment. Malthusians and neo-Malthusians argue that there is a simple negative relationship between population growth and the natural environment (Ehrlich and Holdren, 1971; Meadow et al., 1972; Malthus, 1978), whereas other scholars contend that an increase in populations does not necessarily lead to environmental degradation and resource scarcities (Simon, 1981; Boserup, 1981). Nevertheless, there is widespread consensus that the relationship between populations and environments is complicated (United Nations Population Fund, 1991; Qin, 2009).

Some studies have shown that migration has little or no effect on pollution levels in terms of air quality (Squalli, 2009; 2010) because migrants typically have smaller ecological footprints than locals, producing less pollution (Cramer, 1998; Hunter, 2000; Neumayer, 2006; Bohon et al., 2008; Price and Feldmeyer, 2012; Ma and Hofmann, 2019). Cramer (1998) who investigated the relationship between population growth and air quality in the United States, found that higher concentrations of migrant populations corresponded to lower levels of five major air pollutants. Increasing air pollution was mainly caused by the domestic population rather than by the migrants. Squalli (2009) studied the relationship between four major air pollutants and populations that were native-born and foreign-born based on data obtained from about 200 US counties. His findings indicated that the size of the migrant population was negatively associated with the level of SO_2 and positively associated with the level of CO. However, the size of the US-born population was found to have a significantly positive relationship with levels of NO_2, PM_{10}, and SO_2 (Squalli, 2009). Squalli subsequently examined the same relationships at the level of states in 2010 and obtained similar findings, namely that foreign-born populations were associated with lower emissions of SO_2 and NO_2 compared with native-born populations (Squalli, 2010). Price and Feldmeyer examined the effects of migration on local air pollution levels in 183 metropolitan statistical areas. Their findings indicated that population growth resulting from migration did not evidence the same pollution effects as did domestic migration and natural population growth (Price and Feldmeyer, 2012). Some studies have suggested that the first generation of migrants in the United States demonstrated a higher level of environmental concern than native-born residents (Hunter, 2000). Moreover, they were more likely to engage in environmentally-friendly behaviors, for example, carpooling and energy-saving (Hunter, 2000; Takahashi et al., 2018).

In China, there have been few empirical assessments of the impacts of in-migration and urban population growth on environmental pollutant emissions in cities. To the best of our knowledge, only two studies (Qin and Liao, 2016; Rafiq et al., 2017) have examined the impacts of migration on air quality in China. Qin and Liao introduced the STIRPAT model using a two-period (2004 and 2010) panel dataset covering 113 pilot cities in China where environmental protection has been implemented to examine the relationship between interprovincial migration and pollution. Their results suggested that internal migration contributes to air pollution (Qin and Liao, 2016). Rafiq et al. (2017) extended STIRPAT model by expanding the control variables (e.g., energy consumption and FDI) and environmental quality (including air pollution, water contamination, and an aggregated waste measure). They used periodical data with a linear and nonlinear model to explore the relationship between interprovincial migration and pollution (Rafiq et al., 2017). The findings of both of the above studies suggest that internal migration contributes to air pollution. However, these results are not consistent with those of other studies conducted in the United States, which found that migration has little impact on air pollution (Cramer, 1998; Squalli, 2009, 2010; Price and Feldmeyer, 2012). There were two limitations in the above two studies. The first was that only one simple index for the net migration rate was applied to investigate the impact of migration on urban air quality. The second was that the specific impacts of migrant and native populations on urban environments were not assessed. These gaps indicate that a study of the impacts of net migration on China's urban environments would be a valuable contribution to the literature.

In light of the above discussion, we aimed to explore the relationship between net migration and urban environmental pollutant emissions in China based on compiled data. The main contributions of this study are as follows. First, we have proposed a revision to the STIRPAT model for examining the relationship between net migration and urban environmental pollutant emissions by dividing urban residents into two groups: migrant and native residents based on available population data and considering environmental pollutant emission factors. Second, we conducted a detailed analysis of relationships among variables based on the results of the model. Our findings not only effectively demonstrate the relationship between net migration and urban environmental pollutant emissions but they also offer inputs that can improve current urban management and advance future urban development.

2 Data and Methods

In this section, we describe how we constructed a two-period (2005 and 2015) dataset based on data compiled for cities in China, excluding Hong Kong, Macao and Taiwan due to lack of data. The dataset included the environmental pollutant emissions and socioeconomic data for each of the cities included in the study. Below we describe the data sources, analytical procedure, and improved STIRPAT model.

2.1 Data sources

2.1.1 Data on environmental pollutant emissions

Data on environmental pollutant emissions were obtained from the annual reports of the National Urban Environmental Management Program within the Ministry of Ecology and Environment of the People's Republic of China. Five indicators of environmental pollutant emissions were selected for this study: three major air pollutants; Air Quality Index (AQI), which is a composite air pollution index; and the greenhouse gas, carbon dioxide (CO_2). The three pollutants were nitrogen dioxide (NO_2, annual mean, ppm), particulate matter ($PM_{2.5}$, annual mean, μg/m^3), and sulfur dioxide (SO_2, annual mean, ppm). AQI is a comprehensive indicator of urban air quality that encompasses not only the pollutants $PM_{2.5}$, NO_2, and SO_2 but also particulate matter (PM_{10}), ozone (O_3), and carbon monoxide (CO). The AQI value ranges between 0 and 300, with a higher AQI corresponding to poorer air quality. Whereas CO_2 is not harmful for human health, it is the main greenhouse gas propelling global climate change. Hence, CO_2 emissions were also included in this study on environmental pollutant emissions attributed to migrants. Table 1 provides detailed information on the indicators for environmental pollutant emissions.

2.1.2 Socioeconomic data

Socioeconomic data on the cities covered in the study were obtained from the *China City Statistical Yearbook 2006 and 2016* (Department of Urban Socio-economic Surveys, National Bureau of Statistics, 2006; 2016). To examine the relationship between net migration and environmental pollutant emissions, we divided the total population into two categories: migrant and urban native populations. A native population was defined as all residents living in the place of their birth. The migrant population was calculated using Equation (1). The total permanent population comprised the sum of migrant and native populations.

$$PS_t = P_t - P_{t-1}\left(1+i\right) \quad (1)$$

where PS_t denotes the migrant population in year t, P_t is the total permanent population in year t, P_{t-1} is the total permanent population in year t–1 and i denotes the natural growth rate of the total permanent population.

2.2 Methodology

2.2.1 Basic model

In this study, we applied the STIRPAT model as our theoretical and analytical framework. Dietz and Rosa (1994) proposed an improved nonlinear stochastic regression model known as the STIRPAT model based on the IPAT model that has been applied in studies on the relationship between the population and environment (Dietz and Rosa, 1994). The STIRPAT model has been widely used to analyze the determinants of a variety of environmental impacts (York et al., 2003; Fan et al., 2006; Martínez-Zarzoso and Maruotti, 2011; Shahbaz et al., 2016; Haseeb et al., 2017; Yeh and Liao, 2017).

The STIRPAT model is expressed using the following basic formula:

$$I_i = aP_i^b A_i^c T_i^d e_i \quad (2)$$

The logarithmic form is as follows:

$$\ln I_i = a + b\ln P_i + c\ln A_i + d\ln T_i + \ln e_i \quad (3)$$

where I_i, P_i, A_i, T_i represent the environmental pollutant emissions, the population factor, the wealth indicator and the technology indicator of the observation i, respectively; a is the intercept, the log of a from Eq. (2); and b, c, d are the exponents of the driving factors. e_i is the error term. The index i denotes the different observations.

Table 1 Description of the urban air emission index and data sources

Index	Description and damage to people	Pollutant source	Source of data
AQI	A comprehensive index to quantitatively describe the level of air pollution and the pollutant includes PM_{10}, $PM_{2.5}$, SO_2, NO_2, O_3, CO	–	Monthly statistics of prefecture-level cities provided by China's Online Air Quality Monitoring and Analysis Platform (obtained from (www.aqistudy.cn))
SO_2	One of the main pollutants in the atmosphere which is a common colorless gas with a strong pungent smell. It is the main component of acid rain which will cause great damage to crop and buildings	Mainly from the combustion of sulfur rich materials (crude oil, coal and other common metals) in the industrial production process	As above
PM	A mixture of solid and liquid particles suspended in the air, which has become the primary pollutant of air pollution. It has an important impact on human health (causing serious respiratory disease) and atmospheric environmental quality, especially $PM_{2.5}$	Mainly from the motor vehicles, power plant, construction sites and rubbish combustion	As above
NO_2	A toxic, pungent and highly reactive gas, which is harmful to human respiratory tract and is the main substance of acid rain and ground-level ozone	Mainly from motor vehicle exhaust, power plant, boiler exhaust, and the industrial, commercial and residential fuel burning	As above
CO_2	A common greenhouse gas, colorless and odorless which is the main gas in the global warming. It is harmless to human and environment basically	Energy consumption of household in the daily life	China Urban Construction Statistical Yearbook (Ministry of Housing and Urban-Rural Development, P.R.China, 2006; 2016)

We obtained environment emission I based on a consideration of the three air pollutants, namely $PM_{2.5}$, NO_2, and SO_2 along with AQI and CO_2. Thus, the environmental pollutant emissions were expressed as: I_i={AQI, CO_2, SO_2, $PM_{2.5}$, NO_2}. To address our research question, we divided the population variable, P, into two components: migrant population (*MP*) and local population (*UP*), that is, P ={*MP*, *UP*}. The variable A, which was measured by per capita GDP (i.e., *PGDP*) and per capita squared, was used to control the potentially nonlinear relationship between income and emissions. Variable T was not considered a single factor; rather, it comprised diverse factors affecting the environmental put it into the error term impacts. Consequently, we interpreted it as the residual term in the model. The STIRPAT model that we applied to explore the relationship between environmental pollutant emissions and migrants is shown in Equation (4):

$$\ln I_i = a + b_1 \ln MP_i + b_2 \ln UP_i + c_1 \ln PGDP_i + c_2\left(\ln PGDP_i\right)^2 + \ln \varepsilon_i \quad (4)$$

where a is the intercept; b_1, b_2, c_1, and c_2 are parameters to be estimated. ε is the error term.

2.2.2 Extended model

Since migrant populations in different cities with different social and economic attributes has different impacts on the urban atmospheric environment, we developed an extended version of the basic STIRPAT model by adding some variables for examining the differential impacts of migration under different conditions. We attempted to explore three basic attributes: the urban industrial structure, population density, and transportation, which were respectively measured by the proportion of the secondary industry value (*MS*), the urban population density of a municipal district (*PD*), and the scale of public transport (*NV*). The extended model is shown in Equation (5):

$$\ln I_i = a + b_1 \ln MP_i + b_2 \ln UP_i + c_1 \ln PGDP_i + c_2\left(\ln PGDP_i\right)^2 + d \ln MS_i + e \ln PD_i + f \ln NV_i + \ln \varepsilon_i \quad (5)$$

where a is the intercept; b_1, b_2, c_1, c_2, d, e, and f are parameters to be estimated.

We also aimed to investigate the impacts of the level of concentration of a migrant population on the urban atmospheric environment. Therefore, we introduced Equation (6) in which the migrant populations were considered as a proportion of total population (*RMP*).

$$\ln I_i = a + b_1 \ln RMP_i + c_1 \ln PGDP_i + c_2\left(\ln PGDP_i\right)^2 + d \ln MS_i + e \ln PD_i + f \ln NV_i + \ln \varepsilon_i \quad (6)$$

2.2.3 Model design

Prior to conducting the modeling, we performed a correlation analysis to test the independent variables with R-squared (R^2) for each model (Fig. 1). The results showed that the variables of local population (*UP*) and urban transportation (*NV*) were strongly correlated at the 1% level (the correlation coefficient was greater than 0.8), whereas correlations among other variables were low. To eliminate the effects of collinearity, we extended the model by adding *NV* and *UP* respectively.

Because there is a tendency for cross-sectional data to cause heteroscedasticity, we applied a weighted least

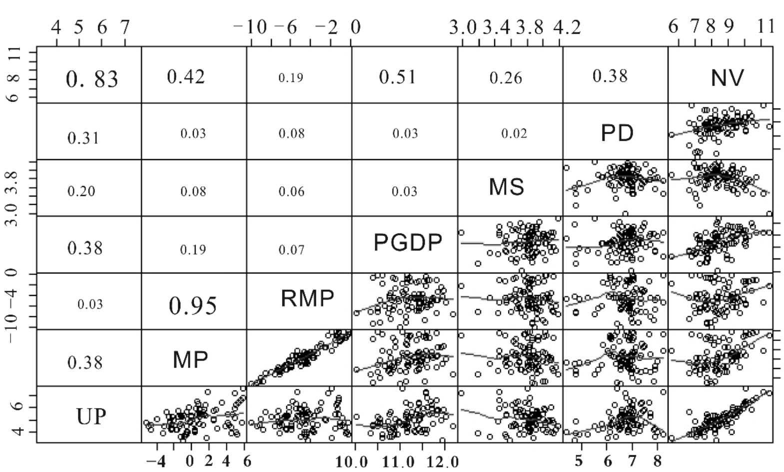

Fig. 1 Correlations of variables in the basic and extended models. Correlation at 0.01 (2-tailed), correlation at 0.05 (2-tailed). UP, local population; MP, migrant population; RMP, ratio of migrant population to total population; PGDP, per capita GDP; MS, proportion of secondary industry; PD, population density; NV, scale of public transportation

squares (WLS) model to estimate the model parameters. Models 1, 2, and 3 were used to analyze the impacts of migrant and local populations on the urban atmospheric environment from the perspective of population size. Model 1 was the basic model in which the sizes of migrant and local populations were considered as explanatory variables. Model 2 was a regression model based on the extended model, which included the urban industrial structure and population density. This model was constructed to investigate the environmental effect of same-sized populations of migrants in cities with different industrial structures and population densities. Model 3 was a regression model constructed using the urban transportation variable to investigate the varying environmental effects caused by the same migrant population under different urban transportation conditions. Models 4 and 5 were constructed to analyze the impacts of migrant populations from the perspective of the level of their concentration. They differed in that model 4 was the basic model in which the proportion of migration was considered as the independent variable, whereas model 5 was an extended model that also included the industrial structure, population density, and urban transportation.

3 Results and Discussion

3.1 Distribution of urban environmental pollutant emissions and migrant populations within prefecture-level cities

3.1.1 The distribution of environmental pollutant emissions in the cities

We first calculated the mean and standard deviation of environmental pollutant emissions in all of the cities. Next, we divided the cities into four groups. Accordingly, as shown in Fig. 2, the four groups were respectively defined as those with low, lower-middle, upper-middle, and high levels of environmental pollutant emissions. It can be seen that the cities with upper- middle

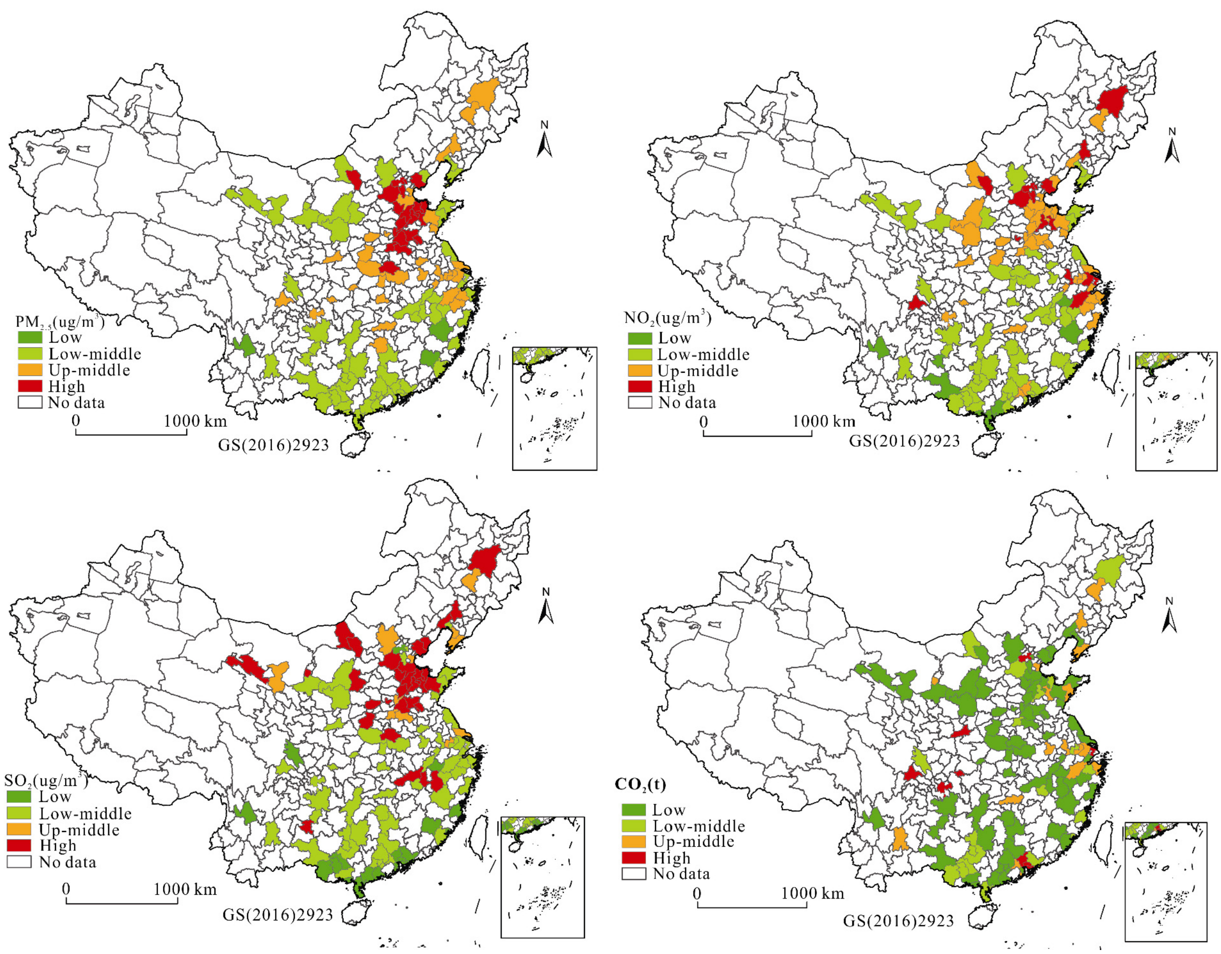

Fig. 2 Air pollution indexes of cites with net in-migration in 2015

and high levels of $PM_{2.5}$ and NO_2 emissions were spatially concentrated and relatively similar. They were mainly distributed in the Beijing-Tianjing-Hebei region, Harbin-Changchun region in the northeastern China and the Yangtze River Delta. The spatial distribution of cities with high and upper-middle levels of SO_2 emissions was evidently also concentrated in the northern China. Moreover, the northern cities of Shangrao and Jiujiang, in Jiangxi Province, which are the main destinations for the relocation of industries, evidenced higher levels of SO_2 emissions. Cities with high CO_2 emissions were Shanghai, Beijing, Tianjin, Xi'an, Changsha, Guangzhou, Chongqing, Chengdu, Shenzhen, Dongguan, Foshan, and Nanjing, all of which are mega cities or metropolises with total populations exceeding 5 million. Due to the sizes of their populations, these cities consume significant amounts of energy, resulting in their high CO_2 emission levels.

A lower AQI value corresponds to a higher level of air quality and vice versa. An AQI value above 100 is indicative of increased health hazards for residents, causing them greater concern. As depicted in Fig. 3, in 2005, there were only a few cities with API values above 100. However, in 2015, there was an evident increase in the number of cities with AQI values above 100. Moreover, air pollution in the target cities located in the northern China was greater than it was in the southern cities. The northern cities with heavy air pollution are concentrated in the urban agglomerations of Beijing-Tianjin-Hebei, Zhongyuan, and Harbin-Changchun. While coal, which is used widely in the northern China, is the main factor accounting for urban air pollution, population agglomeration and economic development are other important factors contributing to air pollution (Xiao et al., 2018). As shown in Figs. 3 and 4, Changchun, Harbin, Beijing, and Baoding have large migrant populations as well as poor air quality, indicated by AQI values above 100.

3.1.2 The distribution of cities with net in-migration

In 2005, out of a total of 284 prefectural cities in China, 203 had net in-migration. In 2015, there was a sharp decline in the number of cities with net in-migration and it is reduced to 112. During the period 2005–2015, 113 cities were transformed from cities characterized by in-migration to those characterized by out-migration while the reverse trend was seen for 22 cities. In addition, only three cities had over 500 000 migrants in 2005, whereas this number had increased to 15 by 2015.

As shown in Fig. 4, in 2005, most cities characterized by net in-migration were distributed in the eastern and central China, with a small number of cities located in the northwestern part of Gansu Province, within the Chengdu-Chongqing agglomeration, and in the north-central part of Yunnan Province. Cities characterized by net out-migration were mainly distributed in the northern China, in the northeastern part of Fujian Province, the southwestern part of Guangxi Province, and in the northern part of Shaanxi Province. The cities characterized by net in-migration were surrounded by those characterized by net out-migration in 2015, implying that China is still undergoing a process of urbanization that entails agglomeration. This finding is consistent with the middle stage of urbanization and the mid-late stage of industrialization posited within economic development theory.

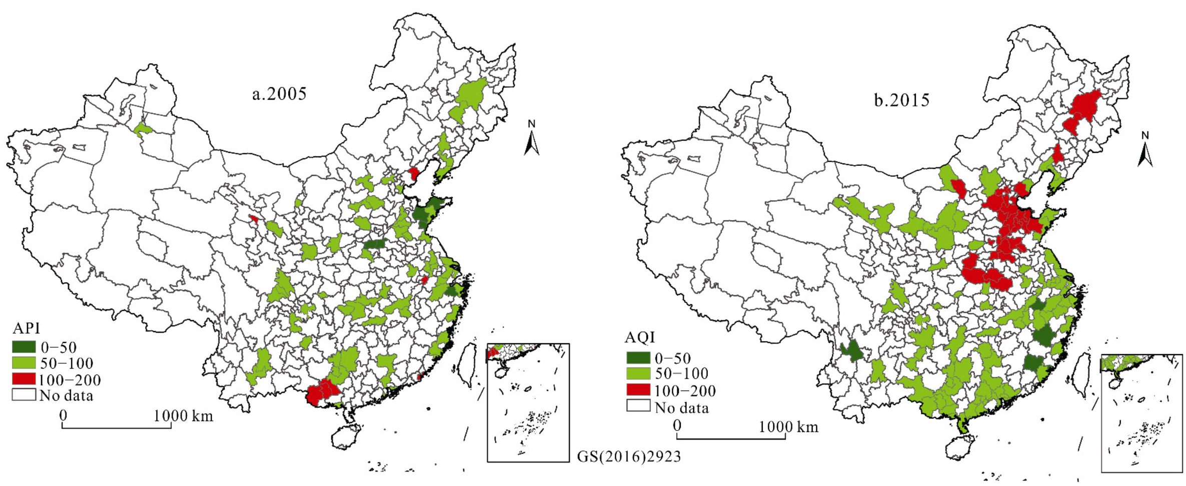

Fig. 3 AQI values of prefecture-level cities with net in-migration in 2005 and 2015

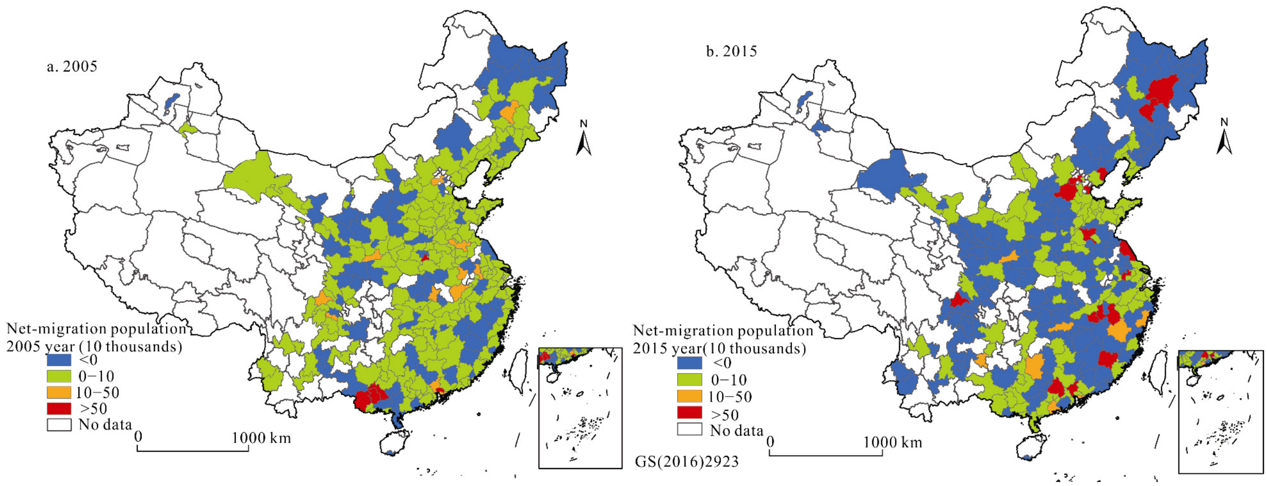

Fig. 4 Net migration size of prefecture-level city in 2005 and 2015

In 2005 as well in 2015, 90 cities characterized by net in-migration were mostly located within the Bohai Economic Circle (including Beijing,Tianjin, Shandong, Hebei and Liaoning) and in the Yangtze River Delta (including Shanghai, Zhejiang and Jiangsu) and Pearl River Delta(including Guangdong) in the east of China, in addition to being dispersed across the northeastern region and the western China (Table. 2).

3.2 Impact of migration on urban environmental pollutant emissions

We used the software EViews version 3.1 to analyze the data. The results of the regression are shown in Tables 3 and 4. As indicated in Table 3, the size of migrant population (*MP*) was negatively associated with the values of AQI and $PM_{2.5}$ at a significance level of 1%, indicating that an increase in the number of migrants had a positive effect in mitigating the deterioration of urban air quality. There was a significant positive correlation between an increased number of migrants and NO_2 and CO_2 emissions, that is, an increase in the migrant population had a positive aggravating effect on concentrations of NO_2 and CO_2. The regression results depicted in Table 4 reveal that the effect of the *RMP* on AQI, $PM_{2.5}$ and CO_2 was similar to that of the *MP*. No significant impact of *MP* or *RMP* on SO_2 was found. Thus, the results showed that migrant populations have a significant effect on urban environmental pollutant emissions both in terms of size and concentration. Next, we present a detailed analysis of our results.

Table 2 List of city with net in-migration population in both 2005 and 2015

Province	Number	City	Province	Number	City
Shandong	13	Jinan, Dongying, Binzhou, Weifang, Qingdao, Liaocheng, Yantai, Weihai, Rizhao, Jining, Zaozhuang, Heze, Dezhou	Guangdong	10	Guangzhou, Foshan, Shenzhen, Huizhou, Zhuhai, Zhongshan, Yunfu, Dongguan, Maoming, Zhaoqing
Henan	7	Kaifeng, Luoyang, Nanyang, Puyang, Shangqiu, Zhumadian, Hebi	Hebei	6	Baoding, Zhangjiakou, Hengshui, Qinhuangdao, Tangshan, Cangzhou
Zhejiang	6	Hangzhou, Ningbo, Zhoushan, Shaoxing, Wenzhou, Jiaxing	Jiangsu	5	Nanjing, Changzhou, Wuxi, Suzhou, Nantong
Liaoning	5	Shenyang, Panjin, Yingkou, Jinzhou, Dalian	Anhui	5	Hefei, Bangbu, Wuhu, Huangshan, Chizhou
Hunan	4	Changsha, Hengyang, Huaihua, Chenzhou	Guangxi	4	Guilin, Liuzhou, Nanning, Beihai
Fujian	3	Fuzhou, Xiamen, Zhangzhou	Jiangxi	3	Nanchang, Shangrao,Jiujiang
Inner Mongolia	2	Baotou, Ordos	Heilongjiang	2	Daqing, Harbin
Shaanxi	2	Xi'an, Yan'an	Yunnan	2	Kunming, Lijiang
Beijing	1	Beijing	Shanghai	1	Shanghai
Tianjin	1	Tianjin	Shanxi	1	Jincheng
Gansu	1	Zhangye	Jilin	1	Changchun
Ningxia	1	Yinchuan	Total	90	–

Table 3 Results of regression models (WLS) by taking the immigrant size as the variable

	AQI			$PM_{2.5}$			NO_2			SO_2			CO_2		
variable	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
C	17.158***	22.686***	20.017***	18.977***	27.393***	27.082***	–1.053	8.800**	–0.427	43.901***	53.441***	45.365***	23.456***	21.161***	–11.070
UP	0.087***	0.088***		0.122***	0.110***		0.155***	0.144***		–0.038	–0.051		1.019***	0.974***	
MP	–0.011***	–0.014***	–0.022***	–0.011***	–0.002	–0.014***	0.005***	0.007**	–0.000	0.007	0.003	–0.004	0.063***	0.069***	0.069***
PGDP	–2.267***	–3.387***	–2.997***	–2.627***	–4.456***	–4.500***	0.602	–1.402**	0.061	–6.964***	–9.007***	–7.728***	–3.855**	–3.402**	2.377
PGDP^2	0.097***	0.145***	0.126***	0.110***	0.189***	0.187***	–0.023	0.065**	–0.006	0.298***	0.387***	0.325***	0.217***	0.197***	–0.077
MS		0.111***	0.261***		0.348***	0.485***		0.219***	0.331***		0.357***	0.636***		–0.212*	–0.145
PD		0.082***	0.015		0.131***	0.089***		0.094***	0.064***		0.123***	0.092***		0.106***	0.048
NV			0.133***			0.159***			0.172***			0.055***			0.831***

Notes: All variables were transformed into their natural logarithms. $^{*}P < 0.1$; $^{**}P < 0.05$; $^{***}P < 0.01$. *C*, constant; *UP*, local population; *MP*, migrant population; *PGDP*, per capita GDP; *PGDP*^{2}, per capita GDP squared; *MS*, proportion of secondary industry; *PD*, population density; *NV*, scale of public transportation

Table 4 Results of regression models (WLS) by taking the immigrant concentration as the variable

	AQI		$PM_{2.5}$		NO_2		SO_2		CO_2	
Variable	Model4	Model 5	Model 4	Model 5	Model 4	Model 5	Model 4	Model 5	Model 4	Model 5
C	22.704***	22.107***	19.088***	26.542***	–1.358	0.718	38.122***	50.183***	–24.089	–21.793*
RMP	–0.014***	–0.023***	–0.010***	–0.014***	0.000	0.002	0.002	0.001	0.061***	0.047***
PGDP	–3.239***	–3.350***	–2.624**	–4.402***	0.685	0.009	–5.913***	–8.552***	4.745*	4.250**
PGDP^2	0.143***	0.141***	0.113**	0.182***	–0.022	–0.003	0.249***	0.361***	–0.128	–0.165*
MS		0.239***		0.489***		0.332***		0.619***		0.003
PD		0.024		0.088***		0.065***		0.087***		0.037
NV		0.116***		0.149***		0.172***		0.053****		0.891***

Notes: All variables were transformed into their natural logarithms. $^{*}P < 0.1$; $^{**}P < 0.05$; $^{***}P < 0.01$. *C*, constant; *RMP*, ratio of migrant population to total population; *PGDP*, per capita GDP; *PGDP*^{2}, per capita GDP squared; *MS*, proportion of secondary industry; *PD*, population density; *NV*, scale of public transportation

3.2.1 $PM_{2.5}$

Table 3 shows that the respective regression coefficient values of *MP*, calculated using model 1, and of *RMP*, calculated using model 4 (listed in Table 4), were –0.011 and –0.010. These values indicate that both the size and concentration of migrant populations have negative effects on $PM_{2.5}$ emissions. Moreover, they suggest that a larger migrant population size or a higher concentration of migrants may lead to lower quantities of $PM_{2.5}$ emissions. This finding is consistent with our expectation and with Squalli's (2009) finding. China is still undergoing a rapidly escalating process of urbanization and development characterized by influxes of predominantly rural migrants into urban areas, with only a small proportion of migrants comprising skilled white-collar workers from other urban areas. Given low incomes and limited rental budgets, migrants tend to rent apartments in villages located within urban areas where access to work is convenient. In their study of migrants living in China's capital, Beijing, Zhao et al. (2018) found that the migrants usually lived in settlements on the peripheries of cities as these areas were closer to the workshops where they worked. Residences located in proximity to these workshops not only reduce the transportation distance but also decrease the likelihood of usage of motor vehicles, which are the main source of $PM_{2.5}$ emissions, given that most migrants prefer to walk to work or use bicycles, motorcycles, or bus transit (Hu, 1990; Zhao et al., 2018).

However, although *MP* and *RMP* are associated with $PM_{2.5}$ emissions, their influence on these emissions is weak. As revealed by the results depicted in Tables 3 and 4, an increase in the size of the migrant population by 1%, corresponded to a decrease in $PM_{2.5}$ emissions by 0.011%. An increase in the proportion of the total migrant population by 1% corresponded to a decrease of 0.01% in $PM_{2.5}$ emissions.

3.2.2 SO_2 and NO_2

As indicated by the estimation results presented in Tables 3 and 4, there was no relationship between migrant populations and SO_2 emissions, irrespective of the proportions of migrant and native populations. This result implies that the demographic factors included in the model are not the main causes of SO_2 emissions. National environmental statistics for 2015 indicate that the proportion of industrial SO_2 emissions accounted for 83.7% of total emissions in China (Ministry of Ecology and Environment, the People's Republic of China, 2017). However, urban SO_2 emissions have been effectively controlled through the optimization and upgrading of the industrial structure. Environmental monitoring conducted by the Ministry of Ecology and Environment has shown that SO_2 emissions of 47 key cities in China (including Beijing-Tianjin-Hebei) are in line with the National Standard II, indicating that the contribution of migrant populations to urban SO_2 emissions is insignificant.

In our model, the size of the migrant population also had a statistically significant effect on NO_2 emissions. An increase in the size of the migrant population by 1% corresponded to an increase in NO_2 emissions by 0.005%. However, the effect of RMP was not statistically significant.

3.2.3 AQI

Because AQI is a comprehensive indicator of urban air quality, its relationship with migrant populations better reflects the impact of the latter on urban air environments. It is apparent from the regression results shown in Tables 3 and 4 that both the size and proportion of migrant populations have a statistically significant negative relationship with AQI, indicating that urban atmospheric pollution will be abated with an increase in the size or proportion of migrant populations in urban districts. Moreover, the migrant populations will generally mitigate the deterioration of urban air quality because in contrast to native residents, migrants' activities, for example, their usage of cars, is of lower intensity (Yang, 2017), which moderates the overall impact of urban residents on environmental pollutant emissions (Cramer, 1998; Squalli, 2009, 2010; Price and Feldmeyer, 2012; Ma and Hofmann, 2019). In addition, low income levels within migrant populations also lead to lower energy consumption of these residents compared with the energy consumption of local residents, as confirmed by data in the Survey Report on China's Floating Population and Squalli (2009).

3.2.4 CO_2

The results of models 1, 2, and 3 depicted in Table 3, and those of models 4 and 5 depicted in Table 4 show that the coefficients of *MP* and *RMP* were positive. They indicate that both the size and concentration of migrant populations has a positive effect in aggravating CO_2 emissions. In other words, an increase in urban migrant populations is associated with an increase in emissions of CO_2, a greenhouse gas. A few studies have found that population growth promotes technological progress with reduced CO_2 emissions (Squalli, 2010; Price and Feldmeryer, 2012). However, most studies point to a positive relationship existing between CO_2 emissions and population size, with an increase in energy consumption corresponding to the expansion of migrant populations in urban areas (Yeh and Liao, 2017). Therefore, ultimately, there is an increase in carbon emissions. The results indicate that an increase of 1% in the size of migrant populations corresponded to an increase of 0.063% in CO_2 emissions (Table 3). Moreover, an increase of 1% in the proportion of the total migrant population corresponded to an increase of 0.061% in CO_2 emissions.

3.2.5 The differential impacts of natives and migrants on urban atmospheric environments

The results of models 1 and 2 presented in Table 3 show that the migrant and local populations have significantly different relationships with urban environmental pollutant emissions. Local populations, unlike migrant populations, were found to have positive relationships with AQI, $PM_{2.5}$, NO_2, and SO_2, indicating that increases in local populations correspond to increases in urban pollutants. Furthermore, the coefficients in models 1 and 2 revealed differences between local and migrant populations. Thus, the regression coefficient for *MP* was less than that of *UP*. Taking the AQI as an example, the coefficient of the native population was 0.087, whereas that of the migrant population was 0.011, indicating that the former's contribution to the AQI was eight times greater than that of the latter. The same results were observed for $PM_{2.5}$, NO_2, and SO_2. Therefore, although the migrant population was found to have a statistically significant effect on urban atmospheric environment, this effect was incomparable with that induced by the native population.

3.2.6 The effects of migrant populations in cities with varying socioeconomic attributes

The extended model accounted for the differing socioeconomic attributes of the cities in the study. There was no change in the level of statistical significance for the migrant population, but a slight change was observed in the coefficients of migrant populations. All of the model results shown in Tables 3 and 4 indicate that there were positive relationships between environmental pollutant emissions and urban population density (*PD*), the industrial structure (*MS*), and urban transportation (*NV*), respectively. Of these three socioeconomic attributes, *MS* was found to have the highest impact on environmental pollutant emissions. Moreover, the results presented in Table 3 show a significant correlation between PD and AQI as well as CO_2 in the absence of transportation factors (model 2). However, the inclusion of transportation factors in the model (models 3 and 5) resulted in an insignificant association of *PD* with AQI and CO_2. Hence, it can be inferred that the impact of transportation on urban atmospheric environments exceeds that of population density.

4 Conclusions

We examined the association between population (native and migrant residents) and environmental pollutant emissions in Chinese cities with net in-migration. Our main findings are summarized below.

First, our findings relating to AQI support those of existing studies showing that the environmental harm caused by migrant populations is less than that associated with the expansion of native populations.

Second, the impacts of migration are not uniform in relation to environmental pollutant emissions. For example, whereas the size of the migrant population is found to have a negative relationship with the emissions of $PM_{2.5}$, their relationships with NO_2 and SO_2 were positive and insignificant, respectively.

Third, compared with migrant populations, native populations have more significant impacts on AQI, $PM_{2.5,}$ NO_2, and CO_2. Specifically, the degree of the impact of native populations was found to be 8 to 30 times greater than that of migrant populations as a result of higher consumption patterns among the former.

Fourth, the environmental impacts of migrant populations of the same size and concentration in cities with different industrial structures, transportation conditions, and population densities differed. After controlling the size and concentration of migrant populations, we found that the industrial structure of a city had the greatest impact on urban environmental pollutant emissions.

These findings have a number of important policy implications. Native urban residents, whose impacts on environmental pollutant emissions are more significant than those of migrant residents, should be targeted within strategies for managing urban atmospheric environments. Accordingly, continued efforts to control numbers of private cars and to adjust the energy consumption structure (e.g., promoting a shift from coal to the gas) to reduce environmental pollution in Chinese cities is recommended.

Although migrant populations effectively reduce the pace of increase of air pollution in urban areas, the population density of cities associated with expanding migrant populations also has a positive influence on environmental pollutant emissions. Therefore, necessary migrant-related inputs are required to alleviate urban environmental pollution.

A third policy recommendation relates to industry. A higher proportion of secondary industry within the urban economy is associated with a more significant impact on urban air quality, resulting in an increased value for AQI and higher emissions of $PM_{2.5}$, NO_2 and SO_2, and of the greenhouse gas, CO_2. Therefore, it would be reasonable for the government to suspend production by some enterprises in the short term when there is a significant deterioration in urban air quality. However, urban environmental pollutant emissions should be reduced to promote sustainable development, for example, by improving enterprises' production technologies and operations and changing their mode of organization (e.g., through directed transformations and upgrading of urban infrastructure and the establishment of industrial parks along the lines of a circular economy).

Although most studies have shown that migration is negatively correlated with the urban atmospheric environment, the results of this study demonstrate positive relationships between migrants and AQI and $PM_{2.5}$ and, more importantly, they show that migrant populations in cities mitigate air pollution and environmental pressure associated with the growth of urban populations. A major reason for this finding is the existing disparity between natives and migrants in terms of their modes of transportation and the volumes of energy that they consume. Therefore, a key strategy for maintaining air pollution at relatively low levels would be to change existing modes of urban transport. This would require proper urban planning and more reasonable organization of living spaces to maintain low commuting requirements and reduce the environmental costs of urban operations.

To further probe into the relationship between migration and the environment, future research could focus on the following areas.

First, we used macro data to explore the relationship between migration and environmental pollutant emissions. Future studies should examine this relationship at the microcosmic level of the individual. For example, migrants could be subdivided into categories based on the timing and purpose of their migration, levels of social integration, and other relevant variables. Such variables would be the main factors relating to their lifestyles and behavioral changes that would inevitably result in differential impacts on the urban environment.

Second, migrants' influence on urban environments is concentrated within community spaces. However, because China's environmental policy targets counties, incorporating migrants into the management of environmental pollutant emissions poses a challenge. Consequently, there is an urgent need for policies that focus on environmental management at the community level.

Last, this study has primarily focused on elucidating the relationships between net migration and environment. However, the core reason for the differential effects of migrants and natives on the environment requires further investigation. We posit that one possible reason for this differentiation could lie in China's *hukou* (population registration) policy, according to which migrants and natives living in the same area are entitled to different benefits. Moreover, differences in the lifestyles and consumption levels of natives and migrants also affect environmental pollutant emissions. These issues require further exploration.

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