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ORIGINAL ARTICLE

The association between rural–urban migration flows and urban air quality in China

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Abstract In light of the rapid urbanization of the world's population over the past decades, there is a growing concern about the environmental impacts of urban population growth. Rural–urban migration is a particularly important component of the urbanization process in developing countries and is often considered to be detrimental to urban environmental conditions. However, few studies have explicitly examined the presumed negative impacts of in-migration on the natural environment of cities. The continuously increasing volume of rural–urban labor migration in China since the early 1980s has formed the largest population flow in world history. This study links the existing literature on population–environment and urbanization–environment interactions by empirically assessing the relationship between rural–urban migration and urban air conditions in China. A two-period (2004 and 2010) longitudinal dataset for the 113 key environmental protection cities of China was constructed based on multiple data sources. We applied the STIRPAT equation using conventional and spatial panel regression models to examine whether rural–urban migration flows were associated with air pollution in cities. Results show a strong negative association of in-migration with urban air quality even after controlling for the effects of other population, affluence, and technology factors. Findings from this research can contribute to a better understanding of the environmental consequences of rural–urban migration in China, with broader implications for sustainable development research and policies.

Keywords Population dynamics · Urbanization · Environmental change · Air pollution · The STIRPAT model · (Spatial) panel regression

Introduction

Urban areas have become increasingly important in recent research on population and environmental change, especially for developing countries. There has been a rapid urbanization of the world's population over the past decades, while cities are increasingly facing environmental challenges relating to global climate change such as heat waves, floods, and droughts. More than half of the world's population have lived in urban areas since 2009, and according to the projections of the United Nations Population Division, urban residents will account for 67 % of the world population in 2050 (United Nations 2010; 2012). The world population data also show that developing countries have undergone urbanization much faster than developed nations. Rapid urban population growth has become a common significant issue across the developing world. It is estimated that the total urban population of the less developed countries will increase from 2.7 billion in 2011 to 5.1 billion in 2050, while the proportion of urban population relative to total population is projected to increase from 47 to 64 % in the same period (United Nations 2012).

Sources of urban population growth include natural urban population increase, net in-migration, and the

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expansion of city boundaries to encompass more rural population. The bulk of the contemporary world population movement is associated with the population growth in urban areas of low- and middle-income nations (Satterthwaite 2009; Seto et al. 2014). Migration of the labor force from rural to urban areas has been a particularly important component of the urbanization process in developing countries (UNFPA 2008). Rural-to-urban migration has historically accounted for a large part of urban population growth (Chen et al. 1998) and continues to have a key role in the urbanization of the developing world (Lall et al. 2006; United Nations 2011). Although population flows from non-metro to metro areas are not as observable as in historical times in developed countries, this migration trend has continued in industrialized nations such as the United States (Arzaghi and Rupasingha 2013; Fuguitt and Beale 1996).

Urbanization level is generally considered as a key indicator of a country's social and economic development. Concentration of population and economic activities into cities can bring a variety of benefits such as higher labor productivity and larger economies of scale. Yet at the same time, rapidly growing urban population may cause overburdening of infrastructure and services, increasing unemployment, slums and poverty, and higher crime rates (de Sherbinin et al. 2009a). In the current urbanization and environment literature, the relationships between urbanization, population growth, and the natural environment are often described in highly presumptive and aggregated ways. There is a general assumption that high population concentration in urban areas increases pressure on local ecosystems and exacerbates environmental degradation. Since cities are considered as a major contributor to global environmental and climate change, the strongly negative discourse of the environmental impacts of urbanization is seemingly commonsense. Thus far, few studies have empirically assessed the presumed negative impacts of in-migration and urban population growth on the natural environment of cities.

This paper focuses on the relationship between rural–urban migration and urban environmental conditions in China to explore the environmental impacts of urbanization. As the largest developing country and the most populous nation in the world, China holds an important role in the global urbanization process. Its urban population is expected to increase from 682 million in 2011 to 958 million in 2030, a huge growth accounting for 20 % of the total increase in the world urban population over this period (United Nations 2012). Rural–urban migration is currently the main driving factor of urbanization in China (McGranahan and Tacoli 2006; Chan 2011). The continuously increasing volume of rural–urban labor migration in China since the early 1980s has formed the largest population flow in world history. Given the relatively low urban fertility level in China, the contribution of rural–urban migration to urbanization is much higher in China than in other developing countries (Montgomery 2008). According to the latest national survey of migrant workers, there are currently more than 163 million rural labor migrants in China (NSBC 2013). This large-scale population movement has led to profound social, economic, and environmental consequences in both rural origin villages and urban destination areas.

This study links the existing literature on population–environment and urbanization–environment interactions by quantitatively assessing the potential influences of rural–urban migration on one of the most studied aspects of the urban environment, urban air quality. China provides a particularly useful case for integrative research on urbanization, migration, and the natural environment. Addressing the environmental impacts of migration flows in urban centers is critical for China to achieve its strategic goal of sustainable social, economic, and ecological development. Findings from this research can also provide broader implications for sustainable urban development policy in other developing countries which are experiencing rapid rural–urban migration. In the following sections, we first provide an overview of the recent literature on the impacts of urbanization and population growth on the environment and describe our conceptual framework and research hypotheses. The analytical model, dataset, operationalization of conceptual factors, and data analysis procedures are then explained. Next, we present and discuss major findings of this study, and conclude with some remarks on policy and research implications.

Population dynamics and the urban environment

The examination of the interactions between population and the environment has a long history. Malthusian and neo-Malthusian theories suggest a rather simplistic negative relationship between population increase and the natural environment (Ehrlich 1968; Malthus 1798; Meadows et al. 1972). This pessimistic view of the environmental impacts caused by population increase persists despite the absence of consistent empirical evidence. As the pace of urban population growth accelerates in developing countries during recent decades, there is an increasing concern about the impacts of urbanization on the environment. Researchers and policy makers alike have largely taken on the negative paradigm in the population and environment field. Rural–urban migration and the resulting population concentration in cities are often viewed as detrimental to urban environmental quality. Previous studies in different regions of the developing world contend that rapid urbanization leads to severe urban environmental problems including air pollution, water contamination, inadequate waste management and sanitation, unsustainable natural resource use, and the degradation of sensitive ecosystems such as the coastal environment (e.g., Brennan 1999; Hope and Lekorwe 1999; Ichimura 2003; Marshall 2005; Roberts 1994; Torres 2002; White et al. 2009). While urban growth is relatively slower in developed countries, researchers have found urbanization contributes to a range of environmental impacts of cities in such nations, including greenhouse gas emissions, solid waste generation, residential energy consumption, and the overall "ecological footprint"—a comprehensive measure of cumulative environmental impacts (e.g., Clement 2009; Elliot and Clement 2014; Liddle and Lung 2010; York et al. 2003a, b).

The relationships between urbanization and the environment are rather complex (de Sherbinin et al. 2009b), and there is no general consensus on the aggregate environmental impacts of urbanization. Notwithstanding all the negative environmental implications of urbanization, urban population concentration may have a number of beneficial impacts on the environment in cities and adjacent areas. Holding constant human population size, dispersed settlement patterns are more injurious to wild species than urban agglomeration (Pebley 1998). Therefore, population concentration in cities may significantly benefit the conservation of natural areas and biodiversity. Higher population density can improve economies of scale for urban infrastructure, public services, energy consumption, and environmental management (Hardoy et al. 2001; Marcotullio et al. 2012; Romero-Lankao and Qin 2011; Torres 2002), thus reducing overall population pressure on the environment and natural resources. The concentration of population, economic activities, and resources into cities may eventually transition human society toward sustainability (Seto et al. 2010).

Previous empirical research on population as an important driver of environmental change was mostly conducted at the regional and the national levels. Large-scale, cross-national studies showed population growth substantially increased countries' atmospheric emissions and "ecological footprint" (e.g., Rosa et al. 2004; Shi 2003; York et al. 2003a). York and Rosa (2012) advanced these analyses with a longitudinal study of the influences of the number of households and average household size on air pollution during 1990–2000 at the nation level. Their results indicated that changes in the number of households had a larger effect on pollution emissions (particularly SO_2 emissions) than changes in average household size, thereby suggesting the distribution of population across households is as important as its size and growth in population impacts on the environment.

Based on the data for 56 counties in California, Cramer (1998) found population growth strongly contributed to some types of air pollution (reactive organic gases, oxides of nitrogen, and carbon monoxide) between 1980 and 1990. Further specifications of the population factor suggested that domestic increase was much more important than immigration in terms of ecological impacts. Another panel analysis covering all American states also showed a nearly proportional relationship between population size and carbon emissions (Clement 2011). Recent research expands this line of inquiry to the city level by exploring the influencing factors of urban atmospheric emissions and energy consumption using large cross-national datasets (Liddle 2013; Marcotullio et al. 2014a; Romero-Lankao et al. 2009). Population size and density are found to be among the most important drivers of urban environmental impacts in all these studies.

Although the strong relationship between demographic factors and environmental degradation found in previous research is remarkable, there is only limited empirical evidence regarding the role of migration in the effects of population dynamics on the urban environment. Current migration and environment research revolves around two aspects of a reciprocal relationship: the effects of environmental factors on migration (e.g., Bates 2002; Gray 2009; Henry et al. 2004; Hugo 1996; Hunter 2005; Massey et al. 2010), and the environmental consequences of migration. Overall, previous studies on the latter part of this relationship focused on the environmental impacts of migration in rural areas of destination or origin (e.g., Carr 2009; Cassels et al. 2005; de Sherbinin et al. 2008; Qin 2009; Qin and Flint 2012a; Schmook and Radel 2008). A recent meta-analysis study on urban vulnerability to climate and environmental change did not identify any article published during the past 20 years that specifically examined relevant in-migration effects in cities (Romero-Lankao et al. 2012). Our extensive literature search only found one study that conducted a comparable analysis of the impacts of migration on air conditions in urban areas (Price and Feldmeyer 2012). This research revealed international immigration was not related to air pollution levels across 183 Metropolitan Statistical Areas in the United States, but domestic migration and natural population growth had significant negative effects on air quality. These results are largely in line with the county-level findings of Cramer (1998) discussed above.

Several recent studies are relevant here as they analyzed the impacts of migration on land use change at different regional scales. Song et al. (2008) examined the environmental impacts of internal migration flows among Chinese provinces using the normalized difference vegetation index (NDVI) and migration data from national censuses. They found that in-migration was negatively and significantly correlated with vegetation growth from 1982 to 2000, and the relationship was even stronger when controlling for the effects of changes in annual mean temperature and total precipitation. Employing similar methodology and data, Van der Geest et al. (2010) assessed the effects of migration on vegetation cover at the district level in Ghana and had essentially identical findings. Additionally, net migration was shown to be a significantly larger contributor to the county-level cropland loss than natural population increase in the United States (Clement and Podowski 2013).

Since much of the rural–urban labor migration in China concentrates people to the east coastal regions which are highly ecologically sensitive and already heavily populated, it is likely to bring serious adverse environmental consequences in urban destination areas (McGranahan and Tacoli 2006). Urbanization-induced environmental problems in Chinese cities such as air pollution, water shortage, and solid waste have begun to receive growing attention in recent years. This results in a large and fast-growing body of literature on urbanization and the environment (e.g., Chen et al. 2010; Li et al. 2012; Wang et al. 2012), but the existing research mainly consists of case studies of cities or provinces and focuses on the environmental impacts of urbanization rate (usually measured as the proportion of urban population to the total population). To our knowledge, no prior research has empirically evaluated the relationship between the massive rural–urban migration flows and urban environmental quality in China.

Conceptual approach and hypotheses

Neo-Malthusian perspectives of population growth and the environment generally assume that large-scale rural–urban labor migration movement will threaten local ecosystems at destination cities. However, there is no simple negative linear relationship between population growth and environmental degradation since population is not the only factor influencing the natural environment. A widely cited model in the enduring population–environment debate is the IPAT formula (Ehrlich and Holden 1971), in which environmental impacts (I) are the product of the size of the population (P), the level of per capita affluence (A), and the technology used to supply each unit of consumption (T). A new human ecology framework moves beyond this general approach by accounting for economic, social, and political contextual factors in analyzing the effects of population size, growth rate, density, and structure on ecosystems (Dietz and Rosa 1994; York and Rosa 2012). In a similar vein, the mediating factor theory of population and environment emphasizes the socioeconomic, institutional, technological, and cultural factors which may modify the relationships between population change and the environment (de Sherbinin et al. 2007; Liao and Qin 2012; Marquette and Bilsborrow 1999; Qin and Flint 2012a). Adopting these conceptual models, we examine whether rural–urban migration flows are associated with environmental quality in urban areas, and whether the relationship between the two is adjusted by economic affluence and industrial technology. Two hypotheses can be developed based on the new human ecology and mediating variable theoretical perspectives as well as on recent population–urbanization–environment literature. First, it is hypothesized that rural–urban labor migration is significantly negatively correlated with urban environmental conditions. Cities with higher in-migration levels are likely to have lower environmental quality. Second, we expect that the association between rural–urban migration and environmental conditions of cities are mediated by affluence and technology levels that also affect the urban environment. When these factors are accounted for in the analysis, the relationship between migration flows and urban environmental quality will reduce in size and statistical significance.

Methods

The stochastic form of the IPAT model

Although providing a common framework for analyzing the impacts of population on the environment, the IPAT model has been criticized for its conceptual problems and methodological limitations. There are likely to be interactions among population, affluence, and technology (Preston 1996). The equation also has little use for empirical research due to its accounting formulation and tautological nature (Dietz and Rosa 1994). In order to make the IPAT model appropriate for hypothesis testing, it is necessary to convert it into a stochastic form:

$$I = aP^bA^cT^de, \tag{1}$$

where a is a constant that scales the model; b, c, and d are the exponents of P, A, and T; and e is the error term that captures the effects of other factors not included in the model (Dietz and Rosa, 1994). This reformulation of IPAT is named STIRPAT (STochastic Impacts by Regression on Population, Affluence, and Technology) and is usually specified in a logarithmic form:

$$\ln(I) = a + b[\ln(P)] + c[\ln(A)] + d[\ln(T)] + e. \tag{2}$$

Thus, the exponents b, c, and d in (1) can be readily estimated with a linear regression model (2) and can be interpreted as the percent change in environmental impacts corresponding to a 1 % change in any of the driving forces. This provides an intuitive measure of the ecological elasticity of environmental change similar to the elasticity models commonly used in economics (York et al. 2005). The STIRPAT equation has been widely used in both cross-sectional and longitudinal analyses of the effects of population on environmental change (e.g., Clement 2011; Cramer 1998; Liddle 2013; Marcotullio et al. 2014a; Romero-Lankao et al. 2009; Rosa et al. 2004; Shi 2003; York et al. 2003a, b; York and Rosa 2012). Recent research on the ecological impacts of migration has not applied this model or conducted longitudinal analysis. In this study, we use panel regression to estimates the STIRPAT formula as our data includes two points in time.

Sample and data

We constructed a two-period (2004 and 2010) dataset for the 113 key environmental protection cities in China, incorporating information on population, environmental quality, and economic activities from multiple data sources. This representative sample is composed of all the municipality metropolitan areas, capitals of provinces and autonomous regions, and other major cities that hold the most important socioeconomic and political roles in the country (not including the two special administrative districts: Hong Kong and Macao; see Fig. 1). The two specific years of study were selected since they were the only time periods with relevant population data available (further explanations for this provided below). Major sources of the data collected included China censuses, statistical yearbooks at different levels of government, and annual socioeconomic development and environmental protection reports of individual cities. National population surveys provided detailed information about population characteristics and composition, while the materials from statistical and environmental administrations generated abundant data on air pollution, economic development, industrialization, and environmental performance.

Measurement

We used the annual average values of three air pollutants commonly included in recent research on cities and climate change to measure environmental impacts in the analytical model: nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and particulate matter less than 10 μm in diameter (PM_{10}). These pollutants have been regularly monitored by urban air quality assessing stations in major cities of China since 2004, while the average concentration levels (measured in mg/m^3) for the 113 key environmental protection cities are published by the Chinese Ministry of Environmental Protection in its annual reports of national urban environmental management. A composite air pollution index was also developed to test the overall relationship between air quality and migration. The values of the three air pollutants in 2004 and 2010 were first scaled, respectively, to a range of 0–1 by applying the formula which the United Nations Development Program normally uses to develop standard indices: [(actual value − minimum value)/(maximum value − minimum value)] (Klugman et al. 2011). The final air pollution index was then calculated as the average of the three normalized values.

There were two population-related measures in the analysis. The first was population density, operationalized as the number of people per square kilometer. This provided a better measurement than total population for the analysis since we used average pollutant levels as dependent variables and the sample cities varied greatly in size. The second population measure in the model was net migration rate, which is of more interest to the research questions of this study. It was calculated using the following equation. The variable was linearly rescaled to a range above 0 before converted to its natural logarithm.

$$\text{Net migration rate} = \frac{\text{total population} - \text{total number of permanent residents}}{\text{total number of permanent residents}}$$

Information on the total number of permanent residents (people with local household registration status) of cities in China is usually only available in decadal census data. However, the 2005 China City Statistical Yearbook includes data on both total and permanent populations of 2004 for major cities (NSBC 2005). We were also able to calculate these two variables using the county-level data of the 2010 China Census, and thus opted to choose the years of 2004 and 2010 for our data collection and analysis. It should be noted that this operationalization of migration includes migrants from both rural and urban origin areas. Nevertheless, this is the best measurement of in-migration for major cities across the whole country based on currently available data, and should still be a good indicator of rural–urban migration flows since the vast majority of Chinese urban residents without formal local household registration are rural labor migrants (Peng 2011).

Economic affluence was measured as the gross domestic products (GDP) per capita, an indicator widely employed in recent studies adopting the STIRPAT model. Finally, we used per capita industrial product (based on the manufacture and construction sectors) as an indicator of technological efficiency since the industrial structure of a city is directly related to the environmental impacts of production and consumption. Panel regression models generally control for time-invariant factors in the analysis (Allison 2009), such as geographic characteristics and weather patterns. Our data also included several other relevant

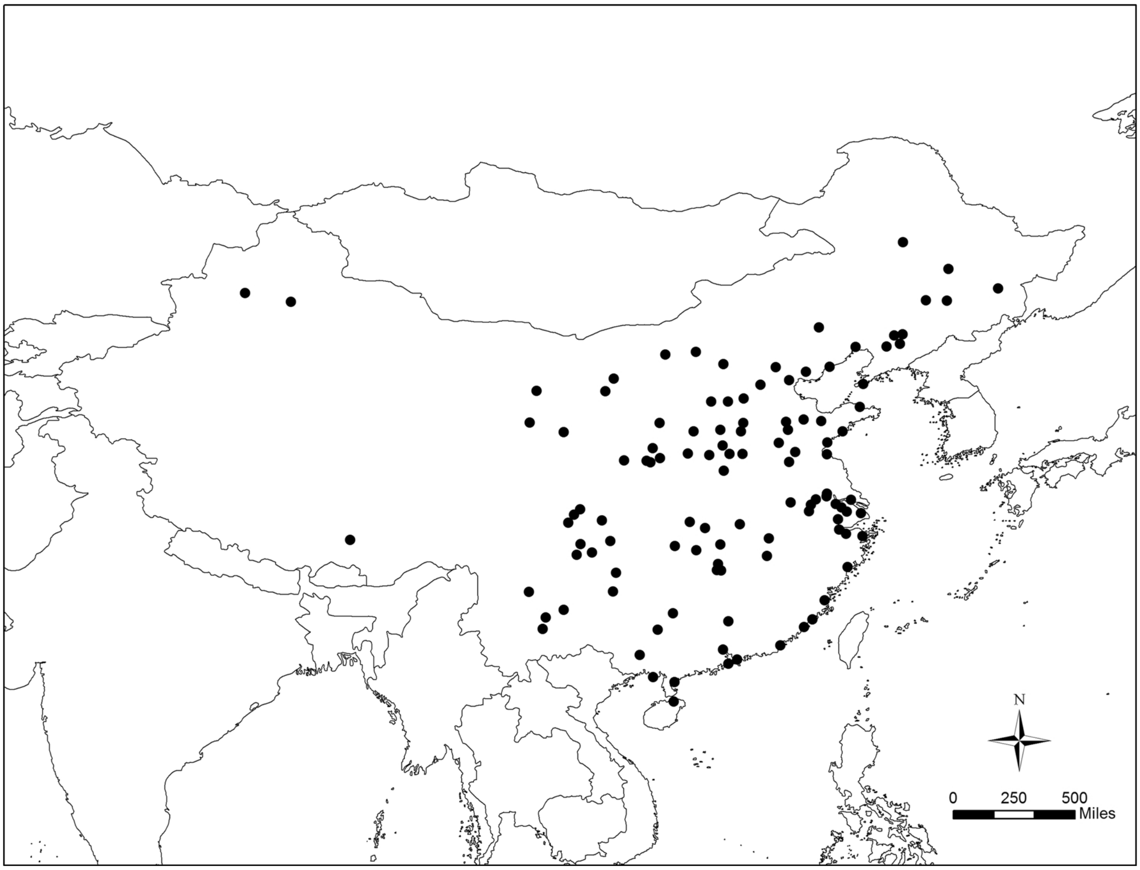

Fig. 1 Map of the 113 key environmental protection cities in China. *Source*: map produced with data from the Center for International Earth Science Information Network—CIESIN—Columbia University, International Food Policy Research Institute—IFPRI, The World Bank, and Centro Internacional de Agricultura Tropical—CIAT. 2011: Global Rural–Urban Mapping Project, Version 1 (GRUMP, v1): settlement points. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://sedac.ciesin.columbia.edu/data/set/grump-v1-settlement-points. Accessed October 9, 2014

variables that could be potentially added into the statistical models, such as GDP per capita squared (to test for a nonlinear relationship between GDP per capita and air pollutants), per capita disposable income, and the proportion of the tertiary economic sector in GDP. They were eventually removed from the analysis because their inclusion did not improve the performance of the models.

Analytical procedures

Descriptive statistics and changes of all the variables during 2004–2010 were explored in the preliminary analysis stage. Next, bivariate correlations among changes in major variables over the study period were assessed with Pearson's r coefficient. Finally, we examined the relationships between city-level net migration rate and individual air pollutants as well as the composite index, applying a panel regression version of the STIRPAT model. All variables were transformed into their natural logarithmic form. For each of the four environmental dependent variables, we initially examined the effect of the migration variable and then included all three control variables (population density, GDP per capita, and per capita industrial product) in the final model. Since our data had a spatial dimension (Fig. 1), there was potential spatial dependence in the variables and error terms. To examine and control this issue in our analysis, we first ran a series of ordinary least squares (OLS) regression analyses of the dependent variables using the 2004 and 2010 data separately, and constructed a k-nearest neighbor ($k = 3$) spatial weights object following the procedures described in Anselin (2003). Residual spatial autocorrelations for these regression models were then tested with Moran's I and Lagrange Multiplier statistics. Standard panel regression models were substituted with appropriate spatial alternatives when significant spatial dependence was detected.

The plm and splm packages of the R software (version 3.0.2) provide useful tools to conduct conventional and spatial panel regression analyses (Millo and Piras 2012). We chose fixed or random effects model for each panel regression analysis based on the result of the Hausman test. The main difference between fixed effects and random effects models is that the fixed effects specification controls for the relationships between observed time-varying predictors and unobserved time-invariant characteristics with stable effects on the dependent variables, while the random effects models assume these two groups of variables are uncorrelated (Allison 2009).

Results

Table 1 presents the means, standard deviations, and changes between 2004 and 2010 for all variables in the analysis. During this period, the average concentration values of all the three air pollutants decreased significantly, and there was a substantial increase for net migration rate, population density, GDP per capita, and per capita industrial product. It should be noted that the mean air pollution indices here reflect the distributions of air pollutant values. The average air pollution index increased during the study period since the distributions of the 2004 SO_2 and PM_{10} data were more positively skewed (with most values concentrated on the left side of the mean) than those of the 2010 data.

Further examination of Pearson's correlations among changes in major variables indicated that the four air pollution measures were highly related with one another (Table 2). Net migration rate was positively and significantly associated with average PM_{10} value and the composite air pollution index. Per capita GDP and industrial product were greatly correlated, and both had a marginally significant relationship with the air pollution index. Moreover, net migration rate was statistically significant in its positive correlation with population density and GDP per capita.

Results of the panel regression analyses of different air pollutants and the aggregated index are summarized in Table 3. We performed a spatial panel regression analysis (including both spatial lag and spatial error) for PM_{10} as the Moran I's test statistics for the residual spatial autocorrelations of its OLS regression objects were statistically significant. Standard panel models were estimated for the other three dependent variables. When only net migration rate was included in the models, it had a significant and positive correlation with NO_2 pollution and the air pollution index, but not with the levels of SO_2 and PM_{10}. After all the variables were added into the analysis, the positive correlations of migration with NO_2 and the composite indicator were even slightly stronger, while PM_{10} value also became significantly and positively related to migration rate. When all other factors remain constant (also assumed for subsequent interpretations of findings), the average NO_2 and PM_{10} concentrations and the air pollution index increase by 0.95, 0.94, and 1.42 %, respectively, for every 10 % increase in the migration level. Population density only had a positive and significant relationship with NO_2 value, with a 0.96 % increase in the NO_2 concentration level corresponding to a 10 % increase in population density. GDP per capita was significant in its negative

Table 1 Descriptive statistics of the variables in the analysis

Variables	Year	*N*	Mean	SD	Mean difference[a]	% of Change
Average NO_2 value (mg/m^3)	2004	113	0.037	0.013	–0.002*	–6.3
	2010	113	0.034	0.011		
Average SO_2 value (mg/m^3)	2004	113	0.062	0.040	–0.020***	–32.3
	2010	113	0.042	0.017		
Average PM_{10} value (mg/m^3)	2004	113	0.119	0.046	–0.031***	–25.9
	2010	113	0.088	0.019		
Air pollution index	2004	113	0.354	0.134	0.064***	18.1
	2010	113	0.418	0.144		
Net migration rate[b]	2004	113	0.150	0.292	0.095***	63.3
	2010	113	0.244	0.351		
Population density (number of people/square kilometer)	2004	113	1398	979	219*	15.7
	2010	113	1617	1550		
GDP per capita (RMB)	2004	113	27,239	13,990	28,541***	104.8
	2010	113	55,780	24,109		
Per capita industrial product (RMB)	2004	113	32,928	24,304	53,187***	161.5
	2010	113	86,114	55,017		

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

[a] Mean differences were assessed using the paired *t* test

[b] The range of net migration rate was linearly rescaled from [−0.224, 3.127] to [0.001, 3.352] before it was converted to natural logarithm

Table 2 Bivariate correlations among changes in the variables in the analysis ($N = 113$)

Variables	1	2	3	4	5	6	7	8
1. Change in average NO$_2$ value	1.000							
2. Change in average SO$_2$ value	0.519***	1.000						
3. Change in average PM$_{10}$ value	0.256**	0.279**	1.000					
4. Change in air pollution index	0.756***	0.651***	0.612***	1.000				
5. Change in net migration rate	0.058	0.107	0.282***	0.199*	1.000			
6. Change in population density	–0.003	–0.008	0.057	0.040	0.238*	1.000		
7. Change in GDP per capita	0.153	0.148	0.083	0.184(*)	0.291**	0.015	1.000	
8. Change in per capita industrial product	0.053	0.150	0.134	0.175(*)	–0.055	–0.177(*)	0.503***	1.000

(*) $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 3 Panel regression models of average NO$_2$, SO$_2$, and PM$_{10}$ concentration values and the air pollution index ($N = 113$)

Variables	NO$_2$ value[a]		SO$_2$ value[b]		PM$_{10}$ value[c]		Air pollution index[b]	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Net migration rate	0.081*	0.095*	–0.053	0.056	0.041	0.094**	0.140*	0.142*
	(0.038)	(0.042)	(0.085)	(0.084)	(0.031)	(0.036)	(0.070)	(0.071)
Population density		0.096**		–0.044		0.002		–0.014
		(0.033)		(0.160)		(0.068)		(0.135)
GDP per capita (RMB)		–0.170*		–0.420*		–0.374***		–0.209
		(0.081)		(0.183)		(0.086)		(0.154)
Per capita industrial product		0.100(*)		0.066		0.111*		0.305**
		(0.054)		(0.129)		(0.056)		(0.109)
R^2	0.102	0.146	0.004	0.214	0.0002	0.391	0.035	0.194
F	25.509***	9.438***	0.387	7.233***	0.029	17.032***	4.004*	6.372***

Given as coefficients of panel regression models (standard errors in brackets). All variables were transformed into their natural logarithms

(*) $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

[a] Standard random effects models

[b] Standard fixed effects models

[c] Spatial fixed effects models. R^2 and F values for the two PM$_{10}$ models were generated with the plm package of the R software (version 3.0.2) as the splm package does not provide such information

relationship with all three types of air pollution. A 10 % growth of GDP per capita is associated with a decrease of 1.70, 4.20, and 3.74 % in NO$_2$, SO$_2$, and PM$_{10}$ levels, respectively. Per capita industrial product was positively correlated with PM$_{10}$ and the air pollution index, and also had an almost significant relationship with NO$_2$ pollutant. For a 10 % increase in this indicator, we can expect a corresponding 1.00, 1.11, and 3.05 % increase, respectively, in the NO$_2$, PM$_{10}$, and pollution index values.

Discussion

The results largely support the hypothesis that in-migration is associated with environmental degradation in urban areas. Other measures of the population, affluence, and technology constructs also had significant correlations with some of the atmospheric pollutants. But contrary to our expectation, migration level was strongly related to all but one of the four air pollution variables even after controlling for the effects of other factors. The magnitude of migration appeared to be particularly associated with NO$_2$ and PM$_{10}$ pollution, and had a weaker relationship with SO$_2$. This is largely consistent with previous findings on the effects of population on different emissions (Cramer 1998). The air pollution levels in our data were aggregated for all sources including both production and consumption activities in cities. The effects of migration on individual emission type depend on the patterns of these sectors and the compositions of pollution sources. Since net in-migration is a key component of urban population growth in China, it should be strongly related to emissions from sources representing consumption and transportation domains (e.g., nitrogen oxides and carbon monoxide) which are directly influenced by population size (Cramer 1998; Romero-Lankao et al. 2009).

Only in the regression analysis of average NO_2 value was the Hausman test statistic in favor of the random effects model, indicating varied relationships between the unobserved time-invariant variables and the observed variables across the models of different air pollutants. We suggest giving more weight to the results of the two fixed effects regression models for the composite air pollution index because they reflect the overall impacts of migration on urban air conditions. Additionally, since this aggregate environmental indicator was based on the normalization of air pollution values from the two respective study periods, the effects of GDP per capita and other unmeasured factors (e.g., changes in national environmental regulations or air quality monitoring protocols) that might contribute to the decrease in air pollution levels across the study cities during 2004–2010 were largely controlled for in these models.

Although we focus on the relationship between rural–urban migration and the urban environment in this research, our results confirm recent research on the significant role of population growth in driving total pollutant emissions and environmental degradation on larger geographic scales. Both migration rate and population density may be considered as proxies of population size in this study as they were highly correlated. The results can also shed light on the differentiated roles of in-migration and natural population growth in the relationships between population change and the environment in urban centers. It is suggested that rural–urban migration is more influential than urban natural increase for the environmental impacts of population dynamics in China and possibly other rapidly urbanizing developing countries.

Rural–urban migration flows can bring forth profound impacts on the natural environment in both destination and origin areas. For the most part, this research can be seen as a logical extension of a recent study on the potential environmental effects of labor out-migration in rural China (Qin 2010; Qin and Flint 2012b). Several other recently published articles also examined the relationships between rural migration and the environment, albeit at different levels of analysis (e.g., Aide and Grau 2004; López et al. 2006; Schmook and Radel 2008; Song et al. 2008; Van der Geest et al. 2010). Taken together, these studies suggest that rural–urban migration contributes to ecosystem recovery and conservation in origin areas but has detrimental effects on environmental conditions in destinations. More integrative assessments encompassing both rural and urban areas are needed in future research to understand the overall environmental impacts of population concentration into cities.

Much of the existing literature on the influencing factors of environmental change focuses on the global scale. While results from such research can help identify common human sources of global climate change, primary determinants of ecological impacts may vary across countries. The findings of this research and those by Price and Feldmeyer (2012) suggest that internal migration contributes substantially to air pollution in both Chinese and American cities. Comparing and synthesizing findings from studies within individual countries can advance our understanding of the diverse driving forces of environmental change and help derive more meaningful implications for public policy and management.

The negative and significant associations found between the three average pollutant values and the affluence measure (GDP per capita) in this analysis can also lend support to the so-called *compatibility* perspectives on the relationships between economic development and the environment such as ecological modernization and urban transition model (Freudenburg 2006; Romero-Lankao et al. 2009). These theories suggest that further economic development in cities brings forth environmental improvement instead of degradation as manufacturing industries are replaced by service sectors in local economies. However, the results show that migration flows were strongly associated with urban air pollution even with the possible benefits of affluence and technological advancement accounted for in the analysis. Furthermore, our findings on GDP per capita do not necessarily represent a trend of transition toward urban sustainability since the dependent variables in the analysis measure local air quality rather than total atmospheric impacts occurring both within and beyond cities' geographic boundaries.

Finally, the analysis revealed that in-migration and population growth were not the only influencing factors of urban air pollution. Per capita industrial product had a relatively greater elasticity value than net migration rate and population density in all the four final regression models. Urbanization is a multidimensional socioecological process driven by changes in demographic, economic, institutional, infrastructural, and biophysical systems within urban areas (Marcotullio et al. 2014b; Romero-Lankao et al. 2014). This multifaceted conception of urbanization dovetails nicely with the new human ecology and mediating factor approaches to the population–environment interactions. Although rural–urban migration and rapid urban population growth form a key dimension of China's urbanization, escalating industrialization and energy consumption are currently the most important drivers of air pollution and carbon emissions in major Chinese cities (Jiang and Lin 2012; Liu et al. 2012).

Conclusions

The connections between migration, urbanization, and environmental change represent a promising area of research for the field of population and the environment. Researchers have shown increased interests in the relationships between cities and environmental (climate) change in recent years. However, thus far, it has been unclear how important migration is to the effects of urbanization on the urban environment. Population size is commonly found to be a significant driver of environmental degradation at the regional, national, and global scales. Our analysis suggests that rural–urban migration flows hold an essential role in the ecological impacts of population growth in Chinese cities. This may also be the case in other developing countries which have similarly high rural–urban migration levels. Findings of this study are consistent with both the new human ecology and the mediating factor arguments. On one hand, as an important component of urban population growth, in-migration level is significantly related with urban air quality in the negative direction. On the other hand, despite the average 63 % increase in net migration rate across the study cities between 2004 and 2010, urban air conditions improved substantially due to the effects of affluence, technology, and other factors such as environmental protection policy. Nevertheless, even if the overall environmental impacts of urbanization decrease along with further economic development and higher technological efficiency, the significant environmental pressure resulting from in-migration and population growth should not be neglected in urban environmental management and planning. While vast rural–urban labor migration will continue to be a major component of the rapid economic growth in China, more balanced regional development patterns and less population concentration in large metropolitan areas should contribute to a more sustainable urbanization process. In a way, this study also provides empirical support for the strategy of promoting population redistribution from eastern mega-urban centers to middle- and small-sized cities in mid-western regions in China's latest Five-Year National Economic and Social Development Plan (NPCC 2011).

While not implying a simplistic causal relation between rural–urban migration and urban air quality, this article explores their possible association for improving the conceptual understanding of migration–environment interactions and the efficiency of relevant policy decision making. Although our results show a strong negative relationship of in-migration with the urban environment, the interconnections among the factors in the STIRPAT equation are quite complicated and dynamic. Urban environmental conditions may have feedback effects on population growth and migration flows as well. Previous research suggests American counties with more environmental hazards (e.g., air and water pollution) receive fewer in-migrants than those less environmentally risk-prone counties (Hunter 1998), while climate change impacts result in higher out-migration rates in the states and municipalities of Mexico (Feng et al. 2010; Saldaña-Zorrilla and Sandberg 2009). It is thus important to collect and analyze longitudinal data with more time points and across different regions to further improve our understanding of the anthropogenic causes and consequences of environmental change in urban areas.

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