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Impacts of rural worker migration on ambient air quality and health in China: From the perspective of upgrading residential energy consumption

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ABSTRACT

In China, rural migrant workers (RMWs) are employed in urban workplaces but receive minimal resources and welfare. Their residential energy use mix (REM) and pollutant emission profiles are different from those of traditional urban (URs) and rural residents (RRs). Their migration towards urban areas plays an important role in shaping the magnitudes and spatial patterns of pollutant emissions, ambient $PM_{2.5}$ (fine particulate matter with a diameter smaller than 2.5 μm) concentrations, and associated health impacts in both urban and rural areas. Here we evaluate the impacts of RMW migration on REM pollutant emissions, ambient $PM_{2.5}$, and subsequent premature deaths across China. At the national scale, RMW migration benefits ambient air quality because RMWs tend to transition to a cleaner REM upon arrival at urban areas—though not as clean as urban residents'. In 2010, RMW migration led to a decrease of 1.5 μg/m^3 in ambient $PM_{2.5}$ exposure concentrations (C_{ex}) averaged across China and a subsequent decrease of 12,200 (5700 to 16,300, as 90% confidence interval) in premature deaths from exposure to ambient $PM_{2.5}$. Despite the overall health benefit, large-scale cross-province migration increased megacities' $PM_{2.5}$ levels by as much as 10 μg/m^3 due to massive RMW inflows. Model simulations show that upgrading within-city RMWs' REMs can effectively offset the RMW-induced $PM_{2.5}$ increase in megacities, and that policies that properly navigate migration directions may have potential for balancing the economic growth against ambient air quality deterioration. Our study indicates the urgency of considering air pollution impacts into migration-related policy formation in the context of rapid urbanization in China.

1. Introduction

Rapid urbanization in China has attracted hundreds of millions of people into cities during the last three decades (National Bureau of Statistics of the People's Republic of China, 2014; Yang et al., 2013). Among these newly-settled migrants, growing numbers of rural migrant workers (RMWs) have received much attention from the government and the public (Ru et al., 2015; Shi, 2008; Wong et al., 2007; Zhao, 1999). RMWs are individuals registered with rural identity (in the Chinese household registration system) and employed in urban

Abbreviations: RMWs, rural migrant workers; REM, residential energy use mix; $PM_{2.5}$, fine particulate matter with a diameter smaller than 2.5 μm; C_{ex}, ambient $PM_{2.5}$ exposure concentration calculated as ambient population-weighted $PM_{2.5}$ concentration; URs, urban residents; RRs, rural residents; EF, emission factor

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workplaces (Wong et al., 2007; Zhang and Shunfeng, 2003). Statistics from the 6th National Census indicated that the number of RMWs in China was 138 million in 2010, or 40% of the urban working population (National Bureau of Statistics of the People's Republic of China, 2016). 58% of the RMWs are within-province who work in the provinces where they are registered; the remaining 42% are trans-province RMWs who migrate from one province to another. The preferred destinations of trans-province RMWs are large (population between 1 million and 10 million) and mega- (population greater than 10 million) cities with more job opportunities and relatively high levels of income. In five Chinese megacities (Beijing, Tianjin, Shanghai, Guangzhou, and Shenzhen), one-third of their urban population on average is RMWs. The percentage is the highest in Shenzhen, where RMWs account for 60% of its population (National Bureau of Statistics of the People's Republic of China, 2016).

RMWs have contributed substantially to recent economic growth in China (Shi, 2008). However, they remain marginalized in urban society (Meng and Zhang, 2001; Shi, 2008; Wong et al., 2007). Most RMWs live in privately built shanties in urban villages (Feng et al., 2002; Ru et al., 2015). The registration system and their minimal wages block their access to social welfare and urban energy infrastructures (Chan and Zhang, 1999; Chan, 2010; Ru et al., 2015). Differences in living conditions between RMWs and registered urban residents (URs) who hold an urban identity lead to disparities in residential energy use mix (REM) (the amount and structure of direct energy consumed for daily residential cooking, heating, lighting, and household appliance operation) (Shen et al., 2017). Residential emissions have been found to be one of the major sources of various air pollutants (Huang et al., 2014; Lei et al., 2011; Ohara et al., 2007; Shen et al., 2013; Wang et al., 2012). Ru et al., 2015 reported that RMWs in Beijing tend to use more coal for cooking and heating than registered URs because natural gas and centralized heating systems are less accessible (Ru et al., 2015). Consequently, per-capita pollutant emissions of RMWs are different from those of URs, though their contributions to air pollution have been poorly understood. The inflow of RMWs into urban regions also leads to large-scale relocation pollutant emissions (Shen et al., 2017), thereby reshaping the geographic distributions of both pollutants emissions and population exposure. Elucidating the impacts of RMWs' migration on ambient air quality in urban and rural areas is critical for addressing public health concerns from air pollution exposure in the context of rapid urbanization in China (Gong et al., 2012).

In our previous study, we investigated the impact of overall population migration on ambient air quality in China with a focus on residential and transportation sectors (Shen et al., 2017). All migrants, comprised of RMWs and newly-registered URs, were included. Our results suggested that migration is favorable for reducing ambient national $PM_{2.5}$ concentrations, as migrants generally shift to cleaner REMs after settling in cities (Shen et al., 2017). Here, by incorporating more detailed data, we further examine the impacts of RMW migration alone. Given the low vehicle ownership among RMW population, we assume little impacts of RMW migration on the transportation source and focus solely on residential emission sources. We use a chemical transport model (Grell et al., 2005) and the Integrated Risk Function (Burnett et al., 2014) to evaluate the impact of RMW migration on ambient $PM_{2.5}$ concentrations and quantitatively assess the cross-province health impacts due to RMW migration.

2. Methods

2.1. County-to-county RMW migration data

Our previous study established a dataset containing the geographic distribution of RMW at the 1-km spatial resolution for the year of 2010 (Supplementary Fig. S1) (Shen et al., 2017). On the basis of this dataset, here we derived detailed origin and destination information from census data to characterize population movements. Data from the 6th National Census (National Bureau of Statistics of the People's Republic of China, 2016) were used in this study: the county-level census data that covers the entire population and the province-level long-table sampling survey data that covers 10% of the total population. The county-level census data provides information for each county, on the numbers of the migrants who migrated within this county (herein referred as *NM1*), migrated from other counties but within the same province (*NM2*), and migrated from other provinces (*NM3*). The long-table survey data classified all migrants into four groups: rural-to-urban migrants (i.e. RMWs in this study), urban-to-urban migrants, rural-to-rural migrants, and urban-to-rural migrants. For each group, the data provided a province-to-province population movement matrix (National Bureau of Statistics of the People's Republic of China, 2016). We integrated the information from these two datasets and derived county-to-county RMW migration matrix containing quantitative and directional information on RMW migration for the year 2010 (Supplementary Text and Supplementary Data).

2.2. RMWs' REM consumption data

Due to the lack of RMWs' REM data from official statistics, we conducted two-stage questionnaire surveys (comprised of community and intercept stages) to determine RWMs' REM. The questionnaire survey framework was summarized in Supplementary Fig. S2. The questionnaire covers information on personal and family (including year of arrival, family size, family members, and income), residence information (including current address, original address, housing type, and housing expenditure), and energy use (including energy types and expenditures for cooking and heating, possession of electricity appliances, and total expenditure on electricity). A sample of the questionnaire is listed in Supplementary Fig. S3 showing the detailed information on various energy types being investigated. These energy types were then aggregated to six major types comprised of coal, liquefied petroleum gas (LPG), natural gas, electricity, heat, and biomass based on a price-to-energy conversion following the method of a previous study (Ru et al., 2015). The community stage is to distribute questionnaires within study cities, and the intercept stage is to conduct face-to-face interviews to validate the representativeness of the survey (see Supplementary text and Supplementary Fig. S2 for survey framework and sample selection criteria). Previous studies found a decrease in life expectancy due to sustained exposure to air pollution from centralized heating in northern cities in China (Chen et al., 2013; Zhang and Smith, 2007). Thus, we collected questionnaires among RMWs in Beijing and Guangzhou, representing northern (with centralized heating) and southern (without centralized heating) China, respectively, to determine REMs for RMWs. A total of 1700 questionnaires were distributed during the community stage with 526 valid questionnaires being collected. Our intercept surveys collected 491 valid questionnaires through face-to-face interviews. Comparison between REMs derived from the two survey stages confirmed the sample representativeness (Supplementary Fig. S4). Combining the two stages, a total of 1017 questionnaires were used for data analysis. The origins of the surveyed population showed a similar pattern to that reported in the sixth National Census in both cities (Supplementary Fig. S5). For other provinces, we estimated RMWs' REMs based on the compositions of RMWs' original provinces and the origin-specific REMs obtained from the surveys. Provinces with and without district heating were adjusted separately using data collected in Beijing and Guangzhou, respectively. Detailed information on the survey conducted in Beijing can be found in a previous study (Ru et al., 2015). For registered urban (URs) and rural residents (RRs), their corresponding REMs were directly derived from the government statistics by province (Ministry of Agriculture of the People's Republic of China, 1997–2008; Energy Statistics Division of National Bureau of Statistics, 1986–2013). This study focuses on REM consumption, whereas direct and indirect emissions from other sectors such as transportation and construction sectors may be also affected by