Air pollution, economic development of communities, and health status among the elderly in urban China.

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Original Contribution

Air Pollution, Economic Development of Communities, and Health Status Among the Elderly in Urban China

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In Western societies, the impact of air pollution on residents' health is higher in less wealthy communities. However, it is not clear whether such an interaction effect applies to developing countries. The authors examine how the level of community development modifies the impact of air pollution on health outcomes of the Chinese elderly using data from the third wave of the Chinese Longitudinal Health Longevity Survey in 2002, which includes 7,358 elderly residents aged 65 or more years from 735 districts in 171 cities. The results show that, compared with a 1-point increase in the air pollution index in urban areas with a low gross domestic product, a similar increase in the air pollution index in areas with a high gross domestic product is associated with more difficulties in activities of daily living (odds ratio = 1.41, 95% confidence interval (CI): 1.09, 1.83), instrumental activities of daily living (linear coefficient = 0.98, 95% CI: 0.58, 1.37), and cognitive function (linear coefficient = 2.67, 95% CI: 1.97, 3.36), as well as a higher level of self-rated poor health (odds ratio = 2.20, 95% CI: 1.68, 2.86). Contrary to what has been found in the West, Chinese elderly who live in more developed urban areas are more susceptible to the effect of air pollution than are their counterparts living in less developed areas.

aged; air pollution; China; health; social change

Abbreviations: CI, confidence interval; CLHLS, Chinese Longitudinal Health Longevity Survey; GDP, gross domestic product; MMSE, Mini-Mental State Examination.

This study contributes to the ongoing discussion on the role of urban economic development in the association between air pollution and individual health status in a non-Western social setting. As China's gross domestic product (GDP) quadrupled between 1978 and 2002 at an annual growth rate of 8%, increased air pollution became a detriment to the health of its citizens. Seven of the 10 most polluted cities in the world are now found in China (1). The history of world industrialization has shown that urban economic development has been accompanied by extensive environmental burdens that have profound consequences on residents' well-being (2–4). Both short- and long-term adverse effects of air pollution on individual health are well documented in the literature and include upper respiratory infections, lung cancer, heart disease, and damage to nerves and the brain (5–9).

Most of these studies, however, follow an ecologic design, which is based on correlations between air pollution in a given area and health outcomes at the population level, such as mortality rates, rates of specific diseases (e.g., respiratory and cardiovascular diseases), and hospital admissions. Individual characteristics are not controlled for even though research has shown that the effect of air pollution depends on individual characteristics, including age, sex, and lifestyle (10). As a result, it is critical to adjust for potentially confounding factors at the individual level (9, 11).

Furthermore, most studies that have explored the interaction effect between community economic status and air pollution on individual health have been limited to Western societies. Most findings suggest that air pollution has a greater impact on people living in economically disadvantaged communities, which may be attributed to higher exposure to air pollutants, lack of access to health care, and greater susceptibility to the detrimental effect of pollution (12, 13). It is not clear, however, whether such findings can be generalized to

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countries that are at a different stage of economic development. In addition, few studies have focused on the elderly population, which is a fast-growing segment in both developed and developing countries. The elderly are more susceptible to harm from toxic substances because of their depressed immune systems, existing diseases, and the accumulation of toxic agents in their bodies (14, 15). In this study, based on a large-scale survey of the elderly in China, we address the following questions: 1) Is there an independent effect of air pollution on the health status of the elderly after individual characteristics and community economic development are controlled? 2) How does economic development modify the effect of air pollution on health status?

MATERIALS AND METHODS

Study population

This study uses data from the third wave of the Chinese Longitudinal Health Longevity Survey (CLHLS) in 2002. The first wave of the CLHLS in 1998, which included only seniors aged 80 or more years, covered 22 provinces in China, where more than 85% of the national population reside. The respondents were followed up in the second wave in 2000. In the third wave in 2002, the CLHLS added younger elders aged 65–79 years to the original respondents, resulting in a sample size of 15,940. All the respondents in the 2002 wave were interviewed between April and October. Specific timeframes varied by province. Information was obtained through in-home interviews. To include the elderly of all ages, we use only the third wave of the CLHLS in this analysis. Because pollution data are available for urban areas only, where the concentration of pollution is usually higher compared with rural areas, individuals living in rural areas are excluded from this analysis. The final sample includes 7,358 elderly residents living in 735 city districts from 171 cities (refer to Web Appendix 1 for distribution of city districts). (This information is described in the first of 4 supplementary appendixes; each is referred to as ''Web Appendix'' in the text and is posted on the *Journal*'s website (http://aje.oxfordjournals.org/).) Systematic assessments of the CLHLS indicate that the data quality is high (16–18).

Health outcome variables

Health outcomes are measured by 4 variables that reflect overall health condition: activities of daily living, instrumental activities of daily living, cognitive impairment, and self-rated health.

The term ''activities of daily living'' refers to the ability to perform any of the following basic personal-care activities: 1) bathing, 2) dressing, 3) eating, 4) indoor transferring, 5) toileting, and 6) continence. Because its distribution is highly skewed in this sample, with 66% reporting no difficulty performing any of these activities, we dichotomize it into ''disabled'' (having at least 1 activities of daily living limitation) and ''no limitation,'' with the latter as the reference category.

The term ''instrumental activities of daily living'' refers to the ability to perform any of the following items: 1) visiting neighbors, 2) shopping, 3) cooking, 4) washing clothes, 5) walking 1 km, 6) lifting 5 kg, 7) crouching and standing up 3 times, and 8) taking public transportation. Choices for each item are ''able to do without help,'' ''need some help,'' and ''need full help,'' with scores from 1 to 3, respectively. The final score of instrumental activities of daily living is the sum of all 8 items and ranges from 8 to 24, with higher scores indicating more difficulty.

Cognitive impairment is measured by the Mini-Mental State Examination (MMSE) (19), which covers the following aspects of cognitive functioning: orientation, registration, duplication and design, calculation, recall, naming, and language. It was adapted to the cultural and socioeconomic conditions in China (20). For example, the respondents were asked to name as many foods as possible instead of to write a sentence, which is an impossible task for many members of this age group, many of whom are illiterate. For the current sample, the reliability of the MMSE scale is high (Cronbach's $\alpha = 0.96$). The MMSE score in this sample ranges from 0 to 30, with higher scores suggesting more impairment.

Self-rated health has been shown to be an effective measure of individual health status (21, 22). It is assessed by a general question: ''In general, would you say your health is 1) very good, 2) good, 3) so so, 4) bad, or 5) very bad?'' Because the distribution is skewed (choices of 4 and 5 account for less than 15% of the whole sample), we combine the responses into the following 2 categories: ''poor'' (combining choices 3–5) and ''good'' (combining choices 1 and 2), with the latter as the reference category.

Community socioeconomic status and air pollution measures

Community socioeconomic status is measured by the GDP per capita of each city district in 2000 (23). To capture a possible nonlinear relation between the GDP per capita and individual health outcomes, we used the cutoffs adopted by the World Bank in 2002, which classified countries and regions into 5 categories based on annual income per capita: poverty ($\leq$\$365), low income (\$366–\$745), lower-middle income (\$746–\$2,975), upper-middle income (\$2,976–\$9,205), and high income (>\$9,205) (http://siteresources.worldbank.org/DATASTATISTICS/Resources/OGHIST.xls). Because the highest city district GDP per capita in our sample was about \$2,367, we classified the 735 city districts into 3 GDP categories: low, medium, and high, corresponding to the 3 lowest categories characterized by the World Bank.

Air pollution is measured by the air pollution index at the city level, shared by districts within the same city. The air pollution index is widely used in environmental research as a measure of general air pollution (24, 25). It assesses the concentration of 3 pollutants: sulfur dioxide, nitrogen dioxide, and inhalable particulates (consisting of particulate matter of <10 μm in diameter, carbon monoxide, and ozone) (refer to Web Appendix 2 for details). They are among the most common air pollutants found in China as well as other developing countries (26–28). City air pollution indexes in this analysis were obtained from the Chinese Natural Resources Database (http://www.naturalresources.csdb.cn/zy/english/database.asp), which is managed by the Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences. Since the health outcome variables adopted in this study reflect health status rather than immediate, specific health responses, we used air pollution indexes for the year of 1995 to take into account the chronic or lagged response to air pollution. Research has shown that air pollution could yield significant mid- or long-term effects on health or mortality, but it has been overlooked in the literature (29). The air pollution index is graded from 1 to 7, with lower scores indicating better quality.

Control variables

Weather can be an important potential confounder to the relation between air pollution level and health status. In this study, we added the average temperature of each city in January as a control variable.

We also control the following variables at the individual level (30, 31): Demographic variables include age (centered at age 65 years), sex, and ethnicity (Han vs. non-Han). Individual socioeconomic status consists of education (1–6 years of schooling, 7 years or more, vs. none), occupation (white-collar occupation vs. others), and perceived family economic conditions (good vs. poor). Family network resources include marital status (currently married vs. not married) and the number of living children. Health behaviors include whether the respondent ever smoked (yes vs. no), drank any alcohol (yes vs. no), and regularly exercised (yes vs. no) in the past 5 years. Finally, an index was constructed to measure engagement in leisure activities. It is the total number of 7 activities in which the respondent was regularly involved: gardening, raising poultry or pets, other outdoor activities, reading, playing cards/mah-jong, listening to radio/watching television, and involvement in organized activities. The index ranges from 0 to 7.

Statistical analysis

We applied 2-level hierarchical models to analyze the data (32) to take into account the variability at both individual and city district levels. Specifically, 2-level linear regressions were used to model the 2 continuous outcome variables (instrumental activities of daily living and MMSE), while 2-level logistic regressions were used to examine the 2 binary outcome variables (activities of daily living and self-rated health) (refer to Web Appendix 3 for more details). Two sequential models were fit for the 4 outcome variables. Model 1 examines the main effects of the air pollution index and community socioeconomic status on health outcomes after adjusting for all individual-level factors. Model 2 investigates the interaction effects of the air pollution index with community socioeconomic status. All analyses were conducted by using STATA, version 10.0, software (StataCorp LP, College Station, Texas).

RESULTS

Table 1 describes the characteristics of all variables included in this analysis. Tables 2 and 3 show the results of the multilevel analysis of the 2 continuous outcome variables (instrumental activities of daily living and MMSE scores) in terms of linear coefficients and the 2 categorical outcome variables (activities of daily living and self-rated poor health) in terms of odds ratios, respectively.

In Model 1, for all outcome variables, both community- and individual-level factors are included except for the interactions of air pollution index with GDP per capita. The associations between the air pollution index and all health status outcome variables are highly significant even after GDP per capita and individual characteristics are controlled. Because all the outcome variables measure the likelihood or level of any health problems, such positive associations indicate that a higher air pollution index is associated with a poorer health status. Specifically, a 1-point increase in the air pollution index is associated with a 0.32 (95% confidence interval (CI): 0.19, 0.45) increase in the score of instrumental activities of daily living, a 0.51 (95% CI: 0.27, 0.75) increase in MMSE score, a 25% (95% CI: 1.15, 1.36) increase in the odds of having activities of daily living difficulties, and an 18% (95% CI: 1.09, 1.28) increase in the odds of reporting poor health. The effect of GDP per capita alone is complex. Although a higher GDP per capita seems to be associated with better outcomes for cognitive function and self-rated health, it is also associated with higher likelihood of having activities of daily living difficulties and has no significant effect on instrumental activities of daily living.

The interaction effects of the air pollution index with GDP per capita are added in Model 2. Most of the interactions between the air pollution index and GDP per capita are significant and consistent. Compared with urban areas with a low GDP per capita, urban areas with a medium GDP per capita often demonstrate a greater effect of air pollution on instrumental activities of daily living, MMSE, activities of daily living, and self-rated health, and urban areas with a high GDP per capita have an even greater effect. Specifically, compared with low GDP urban areas, a 1-point increase in the air pollution index is associated with an extra 0.60 (95% CI: 0.21, 0.99) and 0.98 (95% CI: 0.58, 1.37) increase in instrumental activities of daily living in medium and high GDP areas, respectively. The corresponding values are 1.84 (95% CI: 1.15, 2.54) and 2.67 (95% CI: 1.97, 3.36) for MMSE, respectively; 15% (95% CI: 0.89, 1.49) and 41% (95% CI: 1.09, 1.83) for activities of daily living, respectively; and 87% (95% CI: 1.43, 2.43) and 120% (95% CI: 1.68, 2.86) for self-rated health, respectively.

DISCUSSION

Unprecedented economic development coupled with China's massive population has imposed great strain on its environment. This study confirms for China what others have found about the harmful effect of air pollution on individual health. The health effect of air pollution remains significant on all the health outcome variables, including activities of daily living, instrumental activities of daily living, cognitive impairment, and self-rated health, even after individual characteristics and the level of community economic development are controlled.

Table 1. Frequency Distribution of the Study Sample, Chinese Longitudinal Health Longevity Survey, 2002

	Total No.	% (Standard Deviation)	Mean (Standard Deviation)
Community-level factors			
City districts	735		
Air pollution index			3.5 (1.19)
Medium gross domestic product per capita		36.4 (0.48)	
High gross domestic product per capita		52.7 (0.50)	
Average temperature in January, °C			2.2 (7.4)
Individual-level factors			
Respondents	7,358		
Instrumental activities of daily living difficult, no.			14.2 (6.2)
Cognitive impaired, no.			7.7 (9.04)
Activities of daily living difficult		34.0 (0.47)	
Self-rated poor health		22.4 (0.42)	
Other individual-level factors			
Age, years			86.3 (11.40)
Men		43.1 (0.50)	
Non-Han ethnicity		4.2 (0.20)	
1–6 years of schooling		30.3 (0.46)	
≥7 years of schooling		16.4 (0.37)	
White-collar job		14.8 (0.48)	
Good family economic condition		20.5 (0.40)	
Currently married		32.5 (0.47)	
Living children, no.			3.1 (2.07)
Ever smoked in the past 5 years		21.7 (0.41)	
Ever drank alcohol in the past 5 years		23.9 (0.43)	
Ever did exercise in the past 5 years		44.2 (0.50)	
Leisure activities index			2.3 (1.70)

This study found a consistent interaction effect of air pollution and GDP per capita at the city level on various health outcomes. The effect of air pollution, however, is positively, rather than negatively, related to the economic developmental level of the community. In other words, elderly residents living in richer cities are affected more by air pollution than are their counterparts in poorer cities.

This is contrary to what has been documented in contemporary Western societies, where residents living in poorer communities or neighborhoods are found to be more affected by air pollution because of more exposure and higher susceptibility to air pollution (13). For example, in 98 US communities with higher unemployment rates, the effect of exposure to ozone on mortality was also higher (33). As another example, individuals living in lower income areas in Ontario, Canada, were more likely to be hospitalized as the result of gaseous air pollutants (sulfur dioxide and nitrogen dioxide) (34). Similarly in South Korea, the effect of air pollution on asthma hospital visits was elevated for both adults and children in districts with lower average health insurance premiums (35, 36). The contradiction seems to be related to the meaning of regional socioeconomic development in social settings that are at different developmental stages (12). In developed countries, higher socioeconomic status communities are usually linked with cleaner environments and greater distance from hazardous materials. Individuals who live in these communities tend to benefit from an array of socioeconomic advantages. In developing countries, however, economically advantaged cities or communities usually have elevated pollution and degradation of the ecosystem.

The link among community socioeconomic status, pollution, and health in developing countries, nevertheless, is more complex than a linear mediating model, where higher economic development is simply assumed to bring more pollution, which, in turn, leads to poorer individual health. There is an absence of a linear correlation between GDP per capita and the air pollution index among the 735 city districts in this study: Pearson's correlation is negligible, -0.029 ($P < 0.430$) (refer to Web Appendix 4 for more details). This may be explained by the environmental Kuznets curve hypothesis, which assumes an inverted U-shaped relation between pollutants and income per capita (37): In the early stage of industrialization, the rapid growth

Table 2. Coefficients and 95% Confidence Intervals of 2-Level Linear Regressions on Instrumental Activities of Daily Living Difficulty and Cognitive Impairment of the Elderly, Chinese Longitudinal Health Longevity Survey, 2002[a]

Community-Level Variables	Difficulty With Instrumental Activities of Daily Living				Cognitive Impairment			
	Model 1		Model 2		Model 1		Model 2	
	Linear Coefficient	95% Confidence Interval	Linear Coefficient	95% Confidence Interval	Linear Coefficient	95% Confidence Interval	Linear Coefficient	95% Confidence Interval
Air pollution index	0.32	0.19, 0.45***	−0.38	−0.75, −0.02*	0.51	0.27, 0.75***	−1.51	−2.16, −0.86***
Medium gross domestic product per capita (low)[b]	0.02	−0.41, 0.45	−1.86	−3.20, −0.53**	−1.07	−1.86, −0.28**	−6.88	−9.24, −4.53***
High gross domestic product per capita (low)[b]	0.20	−0.23, 0.63	−2.98	−4.32, −1.64***	−1.07	−1.85, −0.29**	−9.74	−12.1, −7.38***
Air pollution index × medium gross domestic product per capita			0.60	0.21, 0.99**			1.84	1.15, 2.54***
Air pollution index × high gross domestic product per capita			0.98	0.58, 1.37***			2.67	1.97, 3.36***

* $P < 0.05$; **$P < 0.01$; ***$P < 0.001$. All P values are 2 sided.

[a] In all the models, control variables include the average temperature in January for each city, age, gender, nationality, education, occupation, perceived economic condition, marital status, number of living children, smoking, drinking, exercise, and leisure activities.

[b] The category in parentheses is the reference category for a categorical variable.

accompanied by greater use of natural resources and emission of pollutants leads to environmental deterioration and increased pollution. In the later stage, as income has risen and the structure of the economy has evolved from a polluting industrial economy to a cleaner service economy, there is a higher preference by people for environmental quality, and the resources and technology are available to make regulatory measures possible. Thus, pollution gradually reaches a point from which it starts to decline. Although skepticism exists about the robustness of this model (38), there is evidence that city/regional-level environmental burdens, which include air pollution such as sulfur dioxide, suspended particulate matters, and nitrous oxides, exhibit a similarly inverted U relation with income (2, 37, 39, 40).

The regional variation in China with respect to socioeconomic development and environmental management, to some degree, reflects such a pattern. Although the Chinese central government has passed environmental laws and regulations, they are enforced by local governments, which may set different priorities between economic development and environmental protection and are constrained by local financial resources. Even though the more developed areas of

Table 3. Odds Ratios and 95% Confidence Intervals of 2-Level Logistic Regressions on Activities of Daily Living Difficulty and Self-rated Health of the Elderly, Chinese Longitudinal Health Longevity Survey, 2002[a]

Community-Level Variables	Difficulty With Activities of Daily Living				Poor Self-rated Health			
	Model 1		Model 2		Model 1		Model 2	
	Odds Ratio	95% Confidence Interval	Odd Ratio	95% Confidence Interval	Odds Ratio	95% Confidence Interval	Odd Ratio	95% Confidence Interval
Air pollution index	1.25	1.15, 1.36***	1.01	0.79, 1.28	1.18	1.09, 1.28***	0.62	0.48, 0.80***
Medium gross domestic product per capita (low)[b]	1.18	0.89, 1.57	0.77	0.32, 1.83	0.82	0.62, 1.07	0.12	0.05, 0.28***
High gross domestic product per capita (low)[b]	1.55	1.17, 2.06**	0.50	0.21, 1.19	0.73	0.56, 0.96*	0.06	0.03, 0.14***
Air pollution index × medium gross domestic product per capita			1.15	0.89, 1.49			1.87	1.43, 2.43***
Air pollution index × high gross domestic product per capita			1.41	1.09, 1.83**			2.20	1.68, 2.86***

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$. All P values are 2 sided.

[a] In all the models, control variables include the average temperature in January for each city, age, gender, nationality, education, occupation, perceived economic condition, marital status, number of living children, smoking, drinking, exercise, and leisure activities.

[b] The category in parentheses is the reference category for a categorical variable.

China suffered from pollution at their early stages of industrialization, they have accumulated more resources that can now be invested in environmental improvement. Pioneer cities in environmental protection in China are those with higher GDP per capita, such as Shanghai, Dalian, and Guangzhou (28, 41). In contrast, cities in poorer areas, although they are catching up in industrial development, still find themselves with limited resources to cope with environmental problems. Therefore, while less developed areas in China are industrializing and experiencing unmanaged pollution, the more developed areas are trying to contain or reduce damage caused by the unchecked pollution of earlier years. These 2 countervailing processes may have closed the gap in air pollution between the more and the less developed areas, which is reflected in the lack of a correlation between regional GDP per capita and the air pollution index.

The discussion above sheds light on why higher community socioeconomic status is *not* necessarily associated with higher pollution in China. The following provides possible explanations for why community socioeconomic status *elevates* the effects of pollution, or why residents in more developed urban areas are more vulnerable to air pollution than are their counterparts in less developed areas.

First, in a historical perspective, this finding is consistent with the environmental risk transition framework: Economic development at its early stage results in increased community health risks. Societies at this stage shift environmental health risks from the household to the community in the form of such things as urban air quality (3). As a result, the severity of health problems continues to rise as income increases, before it levels off at high income levels as in the rich countries. There is historical and contemporary evidence that supports this perspective: rapid economic growth immediately causes health problems, such as disease and death (3, 4).

Second, what matters may not be just the current level of air pollution but also the cumulative or total exposure. The higher effect of air pollution in more developed areas found in this study may be attributed to respondents' higher exposure at an earlier stage of economic development. The chronic effect of air pollution has been documented in the literature. Chronic exposure to particulate air pollution, for example, was observed to be related to a range of cardiopulmonary health outcomes, including respiratory disease and declines in lung functions (8). For some diseases, the latency, or the length of time between exposure and effect, can be as long as 20–30 years (6). The outcome variables examined in this study are general health conditions, which may be more susceptible to long-term exposure to air pollution.

Finally, the magnitude of the effect of air pollution also depends on residents' sensitivity (10). Residents of wealthier areas in São Paulo, Brazil, for example, had a higher relative risk of dying from the effect of particulate matter of less than 10 μm in diameter than did those living in more deprived areas (42). This could be because the former are protected from other preventable causes of death and thus are more vulnerable or sensitive to air pollution, while the latter, facing multiple competitive causes of death, are less affected by air pollution alone. This could also explain the generally larger effect of air pollution in the more developed urban areas in China.

We found in the research literature that health outcomes focused primarily on 3 categories: mortality, direct measures of morbidity (e.g., respiratory infection, pulmonary functions, and bronchial responsiveness), and indirect measures of morbidity from health care utilization (e.g., hospital and emergency room admissions). Although there are studies that link air pollution with self-rated health (33), we found no study that directly looked at the effect of air pollution on activities of daily living, instrumental activities of daily living, or MMSE at the individual level.

Error in the measurement of exposure is a serious limitation in many air pollution studies (10, 43). This study is no exception. Errors may come from both spatial and temporal aspects. Because this study is based on an overall measure of air pollution at the city level, we could not distinguish the effect of each component of the air pollution index. When the analysis is based on large geographic units, it is unlikely to capture pollution exposure at a more local level that has a more direct effect on individuals (43). Further, the effect may change as the size of study areas varies (44). In addition, we cannot accurately assess the exposure duration. It is quite possible that some residents had moved from one community to another, obscuring the connection between pollution exposure and health outcomes. Although the adoption of the 1995 air pollution index was an attempt to capture the possible lagged effect of air pollution on health status in 2002, whether it is an accurate measure of exposure is still questionable. Finally, the cross-sectional design of this study makes it difficult to establish explicitly the time order of causality (9, 45).

Overall, our study reveals the complexity of the interaction between air pollution and community socioeconomic status on health status. The findings suggest that caution is warranted when generalizing from one set of social settings to another because community socioeconomic status may have different meanings and implications.

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