The Effects of PM2.5 on chronic cardio-cerebrovascular diseases and respiratory diseases in different groups

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Abstract. This paper explored the difference of health damage caused by PM$_{2.5}$ among the rural mid-aged and elderly in the same pollution level areas. In addition, the reason for the difference is also discussed. The results indicate that one unit concentration increase in PM$_{2.5}$ is related to a statistically significant 1.82% increase in the probability of suffering chronic cardio-cerebrovascular diseases, respiratory diseases for the low-income individuals. It is 0.0012 higher than those with high income. In addition, the mid-aged and elderly in the areas with high per capita GDP face a higher risk of having the related chronic diseases. Personal health awareness and local medical service infrastructure play positive roles in reducing the health impacts of PM$_{2.5}$.

1. Introduction

The past two decades have witnessed the tremendous economic development taken place in China, together with large quantities of industrial exhaust emission, which caused severe air pollution [1]. The notorious air pollution, which is threatening people's health, has become a serious social problem in China [2]. Previous researches have examined the negative relationship between air pollution and worse health condition in both developed and developing countries, including the United States [3, 4], the United Kingdom [5], China [2][6], Indonesia [7] and so on.

Mid-aged and elderly above 45 in China are the high-risk group for chronic diseases. The morbidity and mortality of cardiorespiratory diseases are higher for rural residents than those for their urban peers. Hence, identifying the negative health influence derives from the serious air pollution on the rural mid-aged and elderly is the first crucial step in air pollution policy making and rural public health improvement.

The lack of social security systems and low medical service quality makes it difficult for rural residents to receive medical care. Furthermore, the diseases caused by air pollution are chronic diseases that need long-term treatment and high healthcare costs. However, does the impact of air pollution on different groups vary with individual economic status, local economic development and medical conditions? The problem is still not well explained.

In this paper, we attempt to answer the following questions: (i) Whether health losses from PM$_{2.5}$ are different among the people, who are living in places with the same pollution level? (ii) Is the gap of socio-economic factors, personal health awareness, and the local medical service infrastructure lead to the different risk of getting diseases in different groups?
2. Hypotheses, method, data and variables

2.1. Hypotheses
The model of demand for "good health" constructed by Michael Grossman assumed that individuals inherit an initial stock of health that depreciates over time and can be increased by investment. Gross investments in health capital are produced through household production functions. The direct inputs include the time of the consumer and market goods such as medical care, diet, exercise, recreation, and housing, etc [8]. Based on the model presented by Grossman, M.L.Cropper(1981) noted that health capital decays at a rate which depends on air pollution[9]. From the view of Grossman and Cropper, we can infer that as health stock depreciated by the damage of PM$_{2.5}$, there will be a health gap among different groups because of different economic status, health awareness, and local medical care quality. Based on the views of Grossman and M.L.Cropper, we develop the hypotheses.

Hypotheses: Under certain conditions, the health impacts derived from PM$_{2.5}$ are different among different groups.

2.2. Methods
We use Probit Regression Model to estimate the relationship between PM$_{2.5}$ and the probability of suffering from the diseases. As the first dependent variable was from the question, “Have you been diagnosed with cardio-cerebrovascular or respiratory diseases in the past two years?” 1 represents “yes” while 0 represents “no”. The dependent variable is a binary selection problem, so the regression is established as follows:

$$\Pr(P=1|X) = \alpha_{PM2.5} + \beta_{aware} + \gamma_{doctor} + \delta_{X} + H_{PM2.5} + A_{PM2.5} + \epsilon_{ijt}$$

Where $\Pr(P=1|X)$ denotes the health status of the respondents, in specifically, P=1 indicates the respondent suffered from the diseases, otherwise P=0, while $i$, $j$, $t$ refers to the code, location and year of the respondents, respectively. PM$_{2.5}$ refers to the PM$_{2.5}$ average concentration of the cities where the respondents lived in the past two years or present year.

2.3. Data
The main database used in this study is from the China Health and Retirement Longitudinal Survey (CHARLS), which was conducted by the National Development Research Institute of Peking University. The dataset is used to analyze the problem of population aging in China, promote interdisciplinary research on the problem of population aging, and provide a more scientific basis for formulating and improving relevant policies in China[10,11]. As for the data of PM$_{2.5}$, we adopt the Global Annual PM$_{2.5}$ Grids from MODIS, MISR, and SeaWiFS Aerosol Optical Depth (AOD) with GWR. It is a data set released by the NASA Socioeconomic Data and Applications Center. The data of control variables at the city level are from the China Urban Statistical Yearbook.

2.4. Variables
Health: The dependent variable was obtained by asking the participants, “Have you been diagnosed with the chronic diseases listed below by a doctor in the past two years?” 1 represents “yes”, while 0 represents “no”.

PM$_{2.5}$: By using ARCGIS software, the PM$_{2.5}$ grids were analyzed for the average concentration of PM$_{2.5}$ at the county level, so that the data could be used for regression analysis. The data is processed with a logarithm to eliminate the influence of the dimension.

Health awareness: The information of the personal health awareness was obtained from CHARLS by asking a question, “Are you now taking any of the following treatments to treat the diseases?” There are four options for the question. Based on the selection of the respondents, we reassigned the values of the respondents’ health awareness. The value for the respondent who took treatments to treat his diseases is 1; otherwise, the value is 0.
Local medical service infrastructure: It takes a long time to prevent and control the diseases caused by air pollution, especially for the mid-aged and elderly living in the rural areas with poor medical service infrastructure, the cost of time and medical services may higher than that in urban. Therefore, their willingness to receive medical treatment is lower when the diseases are at the early stages, while the sicknesses may turn to chronic diseases which cause greater health losses and economic burden. The number of doctors working in the local city is used to reflect the medical service infrastructure, and the data was collected from the China Urban Statistical Yearbook.

Other control variables: This study controls the variables at individual, household, and city levels. The individual characteristic includes personal health awareness, job, age, the number of cigarettes consumed per day, years of receiving education, marriage, and gender. Meanwhile, the variables reflecting household characteristic includes the per capita household income of last year and the number of family members. Furthermore, the variables at city level include the proportion of local secondary industry output to GDP and the number of doctors working in the local city.

3. Results

3.1. Descriptive statistics
Table 1 presents the statistic description of all variables used in the regression. It shows that the percentage of respondents who have been diagnosed with cardio-cerebrovascular or respiratory diseases in the past two years is 11.5%. The average PM$_{2.5}$ concentration in the past two years was 58.446. 60.3% of the respondents had a good awareness of their health status. A majority of the participants were engaged in agricultural (76.2%), and the mean age was 60.34 years. The mean number of cigarettes consumed per day was 5.45. Most of them were illiterate, so the mean years of education they received were 3.87. 86.6% has a spouse, a little less than half were male (47.8%). The mean per capita household income of last year was about 5,320 Yuan, and each family has an average of 3 members. Among the research cities, the mean proportion of local secondary industry output to GDP was 48.94%. About 11050 doctors were working in each subject cities.

| VARIABLES                                    | Definition                                                                 | Mean   | Std.dev |
|----------------------------------------------|---------------------------------------------------------------------------|--------|---------|
| Cardio-cerebrovascular or respiratory diseases | Have been diagnosed with the diseases in the past two years =1, otherwise=0 | 0.115  | 0.319   |
| PM$_{2.5}$                                   | The average PM$_{2.5}$ concentration in the past two years                | 58.446 | 43.287  |
| Health_awareness                             | Take actions to treat chronic diseases. Yes=1, otherwise=0                 | 0.603  | 0.489   |
| Job                                          | Peasant=1; otherwise=0                                                    | 0.762  | 0.426   |
| Age                                          | Age                                                                       | 60.339 | 9.704   |
| Smoke                                        | The number of cigarettes consumed per day.                                 | 5.452  | 10.970  |
| Edu_n                                        | Years of receiving education                                              | 3.867  | 3.394   |
| Marriage                                     | Married, cohabitating=1, otherwise=0                                      | 0.866  | 0.341   |
| Gender                                       | Male=1, female=0                                                          | 0.478  | 0.500   |
| Ave_income                                   | The per capita household income of last year(10,000 Yuan)                 | 0.532  | 1.392   |
| Family_size                                  | The number of family members                                              | 3.014  | 1.650   |
3.2. *Heterogeneous effect of PM$_{2.5}$ on the health of rural mid-aged and elderly*

Income inequality, personal characteristic, and other socioeconomic factors may change the influence degree of PM$_{2.5}$ exposure varies by groups and individuals. In consequence, the estimated results of PM$_{2.5}$ exposure among rural mid-aged and elderly will be provided to explain the influence degree and intrinsic relationship from the socioeconomic perspective.

3.2.1. *Per capita household income difference.* Table 2 presents the estimation results of the effects of PM$_{2.5}$ on the rural mid-aged and elderly with different income levels. By using the chronic diseases of cardio-cerebrovascular or respiratory diseases as the dependent variables, the first row indicates that the increasing concentration of PM$_{2.5}$ poses a significant risk to the health of rural mid-aged and elderly. However, the marginal effects of PM$_{2.5}$ to the probability of related chronic diseases are varied by different income levels. The marginal effect value of the low-income individual is 0.0182 with significance at 1%, which is 0.0012 higher than those with high income. Meanwhile, the significance level of low-income is higher than that of mid-income (5%). The result suggests that the group with low economic status is more sensitive to the health impact derives from PM$_{2.5}$. From the results of the other control variables, we can infer that most of the respondents with low income may engage in agricultural, which makes them exposed to the polluted air longer than their counterparts. Meanwhile, due to the limitation of economic conditions, the rural mid-aged and elderly with low income can not afford the better medical service in urban areas. Their spouses often play an essential role in taking care of them when they get sick because of PM$_{2.5}$ exposure. And local medical service infrastructure has a significance and positive impact on reducing the health risk of the low-incomer.

| VARIABLES      | low_income         | mid_income          | high_income         |
|----------------|--------------------|---------------------|---------------------|
| Ln_PM$_{2.5}$  | 0.0182*** (0.0044) | 0.0138** (0.0064)   | 0.0170*** (0.0058)  |
| health_awareness | -0.0770*** (0.0049) | -0.0797*** (0.0082) | -0.0806*** (0.0081) |
| Job            | 0.0185** (0.0073)  | 0.0141 (0.0091)     | 0.0117 (0.0080)     |
| Age            | 0.0015*** (0.0003) | 0.0014*** (0.0005)  | 0.0011** (0.0005)   |
| Ln_smoke       | 0.0042* (0.0022)   | 0.0102*** (0.0034)  | 0.0026 (0.0031)     |
| Edu_n          | -0.0001 (0.0009)   | -0.0008 (0.0013)    | -0.0012 (0.0011)    |
| Marriage       | -0.0169** (0.0069) | -0.0177 (0.0121)    | -0.0111 (0.0121)    |
| Gender         | 0.0015 (0.0061)    | -0.0104 (0.0098)    | 0.0043 (0.0092)     |
| Family_size    | -0.0014 (0.0016)   | 0.0008 (0.0021)     | -0.0021 (0.0022)    |
| Secondgdp      | 0.0006* (0.0003)   | 0.0000 (0.0005)     | 0.0002 (0.0005)     |
| Ln_doctor      | -0.0123*** (0.0044)| -0.0028 (0.0064)    | 0.0002 (0.0057)     |
| Constant       | -2.4587*** (0.3420) | -2.5799*** (0.6029) | -3.1322*** (0.6607) |
| Wald chi2(12)  | 336.67             | 114.42              | 125.06              |
| Log likelihood | -6330.4025         | -2076.4688          | -1914.9105          |
3.2.2. Per capita GDP difference. Table 3 shows the results of the health consequences of PM$_{2.5}$ on the rural mid-aged and elderly in different areas with different economic development. The results indicate that one unit concentration increase in PM$_{2.5}$ is related to a statistically significant 2.35% increase in the probability of having the related chronic diseases for the mid-aged and elderly in the areas with high per capita GDP, which is 0.004 higher than those in medium per capita GDP. On the contrary, the PM$_{2.5}$ does not have a significant influence on the health risk for the participants in rural areas with low per capita GDP. One possible reason is that, in order to release the environmental pressure in urban areas, some urban industrial enterprises were required to move to rural areas. High-emission enterprises contribute to economic development and cause severe air pollution at the same time. The concentration of PM$_{2.5}$ increases with the development of the local economy, which produces dramatic harm to the health of the local population. While in most cases, low per capita GDP areas locate in the remote mountainous regions without big factories. As a result, the concentration of PM$_{2.5}$ is too low to have a significant impact on the health of the local residents.

Table 3. Estimates of the effects of PM$_{2.5}$ on the rural mid-aged and elderly in different areas with different economic development.

| VARIABLES               | low_pergdp       | mid_pergdp       | high_pergdp      |
|-------------------------|------------------|------------------|------------------|
| Ln_PM$_{2.5}$           | 0.0087(0.0099)   | 0.0195***(0.0072)| 0.0235***(0.0048)|
| health_awareness        | -0.0819***(0.0071)| -0.0823***(0.0071)| -0.0819***(0.0071)|
| Job                     | 0.0099(0.0096)   | 0.0237***(0.0089)| 0.0163***(0.0083)|
| Age                     | 0.0021****(0.0004)| 0.0012****(0.0004)| 0.0010**(0.0004)|
| Ln_smoke                | -0.0002(0.0032)  | 0.0116****(0.0031)| 0.0010(0.0029)   |
| Edu_n                   | -0.0003(0.0012)  | -0.0010(0.0012)  | -0.0007(0.0012)  |
| Marriage                | -0.0132(0.0099)  | -0.0047(0.0107)  | -0.0185*(0.0112)|
| Gender                  | -0.0048(0.0088)  | -0.0116(0.0089)  | 0.0088(0.0087)   |
| Family_size             | -0.0025(0.0019)  | -0.0004(0.0021)  | -0.0015(0.0023)|
| Secondgdp               | -0.0006(0.0005)  | 0.0014****(0.0005)| 0.0005(0.0006)|
| Ln_doctor               | -0.0048(0.0089)  | -0.0205***(0.0081)| 0.0004(0.0060)|
| Ln_ave_income           | -0.0010(0.0018)  | 0.0012(0.0018)   | 0.0012(0.0019)   |
| Constant                | -1.9951****(0.6399)| -2.4121****(0.5015)| -3.4327****(0.6132)|
| Wald chi2(12)           | 176.08           | 173.48           | 177.1            |
| Log likelihood          | -2777.4371       | -2835.6407       | -2722.3925       |
| chibar2(01)             | 16.41            | 12.1             | 13.13            |
| Observations            | 7,985            | 8,101            | 7,951            |

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

4. Conclusions
This paper explores whether there are differences in health damage caused by PM$_{2.5}$ among the rural mid-aged and elderly living in the same pollution level area.
The results indicate that the health effects appear to be slightly different for the rural mid-aged and elderly with different per capita household income and regional economic development status. The findings suggest the marginal effects of PM$_{2.5}$ on the probability of related chronic diseases are varied by different income levels, and the rural mid-aged and elderly with low economic status are more sensitive to the health impact derives from PM$_{2.5}$. For the low-incomers they can not afford better living conditions or medical care services. Furthermore, PM$_{2.5}$ has a significant influence on the health risk for the participants in the rural areas with high and medium per capita GDP, while isn’t significant for those in the areas with low per capita GDP. The severe air pollution caused by the economic development in rural China has made the related diseases burden heavier and heavier.

In summary, personal health awareness and the number of local doctors play essential roles in reducing the adverse health effect of ambient air pollution. The results indicate that the government should enhance residents' health awareness by promoting medical knowledge and increasing the quantity and quality of rural medical infrastructure and medical staff. Furthermore, the degree of damage to the health of rural mid-aged and elderly varies by income and local economic status. Low-income individuals are more likely to expose in the polluted air, which leads to a higher risk of suffering from the related chronic diseases. The finding suggests that projects of medical subsidies or higher medical insurance reimbursement ratio for low-income groups should be carried out to alleviate the health inequality. The mid-aged and elderly in more economically developed areas take on a greater health burden from air pollution, indicating that environmentally friendly production models are urgently needed to alleviate the contradiction between economic development and environmental pollution.

**Acknowledgement**

We would like to extend our sincere thanks to the data provided by the China Health and Retirement Longitudinal Study (CHARLS) research team and the support from the National Natural Science Foundation of China (project number:71773017), Fujian Academy of Forestry Sciences (project number: KH1701380) and Fujian Agriculture and Forestry University (project number: KCXRC414A).

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