Applied Energy Symposium 2020: Low carbon cities and urban energy systems
October 10-17, 2020
Paper ID: xxxx

The heterogeneity effect of SO_2 on depression in China: From individual, family and province perspectives

Xiaodan Han[1,2], Wei Fang [1,2*]

1 School of Economics and Management, China University of Geosciences, Beijing, 100083, China.

2 Key Laboratory of Carrying Capacity Assessment for Resource and Environment, Ministry of Land and Resources, Beijing,100083, China.

ABSTRACT

SO_2 is a common air pollutant, which is harmful to human physical and mental health. This study construct, an individual-family-province three-level linear regression model to reveal the heterogeneity effect of SO_2 pollution and household health care expense on depression. The findings are as follows: (1) 28.73% and 1.91% depression differences are caused by family and province differences. (2) At the family level, the higher the family health care expenditure, the greater the inequality of depression caused by the differences of social status and physical health. (3) At the province level, the depression difference between men and women was smaller under high SO_2 concentration. The inequality in depression caused by education level disparity increased with the increase in SO_2 concentration. The depression difference between individuals with and without chronic disease was larger under high SO_2 concentration. The inequality in depression caused by relative income disparity increased with the increase in SO_2 concentration. This study is helpful for the government to formulate relevant health service policies for depression and promote the equal development of public mental health.

Keywords: SO_2 pollution, depression, heterogeneity effect, hierarchical level model

NONMENCLATURE

Abbreviations	
WHO	World Health Organization
CFPS	China Family Panel Study
CES-D	Center for Empirical Study Depression
HLM	Hierarchical Level Model
ICC	Intra-Class Correlation

1. INTRODUCTION

Depression is one of the most common mental disorders. According to the WHO, depression is ranked as the single largest contributor to global disability (7.5% of all years lived with disability in 2015) (WHO, 2017). The total number of people with depression was estimated to exceed 300 million in 2015 (WHO, 2017). Depression is also the major contributor to suicide deaths, which number close to 800 000 per year globally (WHO, 2017). Depression directly affects the public, work efficiency (Zivin and Neidell, 2013) and even life, which deserves our attention.

SO_2 is one of the most common air pollutants. According to the 2016 China Environmental Quality Bulletin, SO_2 concentrations in 338 prefecture level cities in China range from 3~88μg/m^3. Cities with SO_2 concentration greater than 60μg/m3 accounted for 3%, cities with SO_2 concentration between 20~60μg/m^3 accounted for 40.5%, and those with SO_2 concentration less than 20μg/m^3 accounted for 56.5%. According to the daily standard value of SO_2 (20μg/m^3) stipulated by the World Health Organization (WHO, 2005), about half of the cities in China do not meet the standard. SO_2 is easily oxidized and reacts with water to form sulfuric acid fume, which attaches to particles and enters the human body to cause neuroinflammation and aggravate of anxiety and depression (Li and Zou, 2019).

On the one hand, individuals' mental health is affected by their own characteristics. On the other hand, it is related to the living environment, such as SO_2 concentration. The differences in SO_2 concentration in different regions of China, as well as the differences in family characteristics and individual characteristics, lead different groups to be exposed to different levels of SO_2 pollution (Cai et al., 2017). China's complex social structure and unbalanced development lead to the public exposure to SO_2 pollution at differing levels, which

Selection and peer-review under responsibility of the scientific committee of CUE2020

contributes to the inequality of mental health. Therefore, this study focuses on the heterogeneity of influencing factors of depression under different SO_2 concentrations from the perspective of the individual, family and region. We analyze how the effects of individual characteristics on depression vary with SO_2 concentration in different regions.

2. MATERIAL AND MENTHODS

2.1 Data

This study uses provincial data, family data and individual data. The data type is cross-sectional data in 2016. Family and individual data are from the CFPS (http://www.isss.edu.cn/cfps/) questionnaire for 2016.

In this study, CFPS data were matched with provincial level data to analyze the influential factors of depression from the individual level, family level and provincial level. The main variables are shown in **Table 1**. According to the results of the 2016 CFPS questionnaire, after data cleaning, data for 26,380 individuals from 12,612 families in 25 provinces of China were obtained.

2.2 Methods

The individual-family-province data are cross-level nested data. The traditional linear model based on single level data is not suitable. The HLM is a regression model dealing with nested data. The HLM does not require the homogeneity of variance within each level or the independence of random error among individuals. In addition, the HLM model can analyze both the intra layer effect of micro and macro variables and the inter layer interaction effect of micro and macro variables. In this study, individual depression and individual characteristics data are nested in the family-level data, and the family-level data are nested in the provincial-level data. Therefore, we construct the individual-family-province three-level linear model.

2.2.1 Null model

The null model does not contain any explanatory variables and is used to test whether there are significant inter-level differences in the explained variables. We construct a null model to calculate the decomposition ratio of individual differences in depression at the individual, family and provincial levels. The null model is shown as formula (1).

$$\text{Level 1: } depression = \pi_0 + e, Var(e) = \sigma^2$$

$$\text{Level 2: } \pi_0 = \beta_{00} + \omega_0, Var(\omega_0) = \tau_{00} \quad (1)$$

$$\text{Level 3: } \beta_{00} = \gamma_{000} + \mu_{00}, Var(\mu_{00}) = \tau_{000}$$

Level 1 represents the individual level. depression is the explained variable. The higher the depression score is, the more serious the depression. π_0 is the intercept at the individual level and represents the average score of individual depression. e is the random difference of depression among individuals. Level 2 is the family level. β_{00} represents the average depression at the family level. ω_0 is the random difference in depression among families. Level 3 is the province level. γ_{000} represents the average depression at the provincial level. μ_{00} is the random difference in depression among provinces.

To determine how much of the overall variance of depression is caused by family differences and provincial differences, we calculate the ICC (Shrout and Fleiss, 1979). The ICC value range is 0-1, which can reflect the ratio of intra level variance to the total variance. The ICC calculation formulas at the family level and provincial level are as formula (2) and (3).

$$\rho_1 = \frac{\tau_{00}}{\sigma^2 + \tau_{00} + \tau_{000}} \quad (2)$$

$$\rho_2 = \frac{\tau_{000}}{\sigma^2 + \tau_{00} + \tau_{000}} \quad (3)$$

σ^2 is the variance at the individual level, which indicates the difference in individual depression in one family and province. τ_{00} is the family-level variance, which indicates the difference in depression in different families. τ_{000} is the variance at the province level, which indicates the difference in depression across provinces. ρ_1 represents the proportion of the family-level depression difference in the overall depression difference. ρ_2 represents the proportion of the province-level depression difference in the overall depression difference.

2.2.2 Individual-family-province three-level linear model

Based on the null model, we add corresponding independent variables at the individual level, family level and province level to form the individual-family-province three-level model. The formulas of the model are as follows.

$$\text{Level 1: } depression = \pi_0 + \pi_1 \times gen + \pi_2 \times edu + \pi_3 \times urb + \pi_4 \times social + \pi_5 \times chronic + \pi_6 \times rincome + \pi_7 \times age + \pi_8 \times smoke + e \quad (4)$$

π_0 represents the average depression in one family. π_i, $i = 1, \ldots, 6$, represent the effect of different individual characteristics on depression.

$$\text{Level 2: } \pi_0 = \beta_{00} + \beta_{01} \times med + \beta_{02} \times fincome + \beta_{03} \times fsize + \omega_0$$

$$\pi_1 = \beta_{10} + \beta_{11} \times med$$

$$\pi_2 = \beta_{20} + \beta_{21} \times med$$

$$\pi_3 = \beta_{30} + \beta_{31} \times med$$
$$\pi_4 = \beta_{40} + \beta_{41} \times med$$
$$\pi_5 = \beta_{50} + \beta_{51} \times med$$
$$\pi_6 = \beta_{60} \qquad \pi_7 = \beta_{70} \qquad \pi_8 = \beta_{80} \quad (5)$$

interaction analysis of age and smoke with SO_2 in level 3. In addition, to make the model converge, this study does not consider the interaction across three levels.

Table 1 Variable definitions.

Level	Variable	Definition
Explained variable	Depression	Mental health was measured by the CES-D in 2016. The higher the score was, the more serious the depression.
Individual	Gender	Female=0, male=1.
	Age	Age of respondents, which is calculated by 2016 minus the birth year in the paper.
	Education	Education level of respondents.
	Urban	Urban-rural classification. Rural=0, urban=1.
	Social class	Self-assessment of personal social status in the local area. Social class is composed of five scales. 1 indicates the lowest social status and 5 indicates the highest social status.
	Relative income	Relative income level in the local area was scored in the range of 1–5 from low to high.
	Chronic disease	Do you have a chronic disease in the last six months? No=0, Yes=1.
	Smoke	Smoke or not. No=0, Yes=1.
Family	Med	Household medical expense.
	Family income	Total household income.
	Family size	Total family members.
Province	SO_2	SO_2 concentrations in the atmosphere in 2016. ($\mu g/m^3$)
	Per GDP	Per capita GDP in each province in yuan/person.

As one of the purposes of this study is to analyze the regulatory effect of family health care expenditure on depression, we only analyze the interaction between Med and individual characteristics at level 2.

Level 3: $\beta_{00} = \gamma_{000} + \gamma_{001} \times SO_2 + \gamma_{002} \times perGDP + \mu_{00}$

$$\beta_{01} = \gamma_{010} + \gamma_{011} \times SO_2$$
$$\beta_{02} = \gamma_{020} \qquad \beta_{03} = \gamma_{030}$$
$$\beta_{10} = \gamma_{100} + \gamma_{101} \times SO_2 \qquad \beta_{11} = \gamma_{110}$$
$$\beta_{20} = \gamma_{200} + \gamma_{201} \times SO_2 \qquad \beta_{21} = \gamma_{210}$$
$$\beta_{30} = \gamma_{300} + \gamma_{301} \times SO_2 \qquad \beta_{31} = \gamma_{310}$$
$$\beta_{40} = \gamma_{400} + \gamma_{401} \times SO_2 \qquad \beta_{41} = \gamma_{410}$$
$$\beta_{50} = \gamma_{500} + \gamma_{501} \times SO_2 \qquad \beta_{51} = \gamma_{510}$$
$$\beta_{60} = \gamma_{600} + \gamma_{601} \times SO_2 \qquad \beta_{61} = \gamma_{610}$$
$$\beta_{70} = \gamma_{700} \qquad \beta_{80} = \gamma_{800} \quad (6)$$

We only analyze the interaction between SO_2 and individual characteristics at level 3. As a control variable, perGDP is placed in the β_{00} of level 3. In formula (6), β_{00} equation shows that the average depression of all individuals in each province = the total average of depression in all provinces + the effect of SO_2 concentration on depression in each province + the effect of perGDP on depression in each province + the difference of each province. β_{01} equation shows that the impact of med on depression is affected by the province's SO_2. $\beta_{0i}, i = 1, \ldots, 6$, shows that the influence of individual characteristics on depression in level 2 is affected by the province SO_2. Age and smoke are the control variables of level 1, so there is no

2.3 Results and discussion

2.3.1 Estimation of the model

The ICC of level 2 and level 3 is calculated according to formulas (2) and (3): $\rho_1 = 28.73\%$, $\rho_2 = 1.91\%$. This shows that the differences at the family level have a great contribution to the overall difference in depression, accounting for 28.73% of the total variance of depression. This reflects that the difference between families is an important reason for the difference in individual depression. The provincial difference accounted for 1.91% of the total depression difference. One of the purposes of this study is to analyze how the influence of individual characteristics on depression varies with SO_2 concentration in different regions. Therefore, we further consider the impact of SO_2 on the inequality in individual depression. According to the ICC at the family level and provincial level, there are significant differences in depression between the family level and the provincial level. It is necessary to further quantify the influence of family and provincial factors on individual depression and the interaction between the different levels on individual depression.

2.3.2 Estimation of the 3-level model

Table 2 shows the regression results of the individual-family-province three-level model. # in **Table 2** indicates the regulatory effect.

The third column of **Table 2** shows that the depression score of men is lower than that of women (-2.3998). The regression coefficient of the interaction between med and gender is -9.84e-06, which indicates that med has a negative impact on the gender effect of depression. In other words, the higher the value of med is, the greater the difference in depression between men and women. For social status, the higher the social status is, the lower the degree of depression. The regression coefficient of the interaction between med and individual social status is -4.60e-06, which indicates that med has a negative impact on the social status effect of depression. The higher the med is, the greater the depression inequality caused by the social status gap. This is because the groups with higher social status pay more attention to pollution and are more willing to invest in family health care to avoid health risks caused by pollution. In terms of whether an individual has a chronic disease or not, the regression coefficient of the interaction between med and chronic diseases is 1.61e-05, which indicates that the family health care expenditure has a positive impact on the chronic disease effect of individual depression. This shows that the higher the med is, the greater the difference in depression between individuals with and without chronic disease. Individuals with chronic diseases usually spend more on health care in their families. The higher the med is, the greater the financial burden on individuals. As a result, the individual pressure increases, which leads to more serious depression. The regression coefficient of the interaction between SO_2 and family health care expenditure is 8.75e-07, which indicates that SO_2 concentration has a positive impact on the effect of family health care expenditure on depression.

Table 2 shows the influence of individual characteristics on depression under low and high SO_2 levels. In **Fig 1**, the blue line shows the effect of individual characteristics on depression under low SO_2, and the red line indicates the influence of individual characteristics on depression under high SO_2. We compared the slopes of the red line and the blue line to reflect the depression inequality caused by high SO_2 and low SO_2. Due to space constraints, we only analyze the variables that pass the significance test.

In terms of individual gender differences, the depression score of men is 2.3998 lower than that of women (-2.3998). This is consistent with the results of Clougherty (2010) that women's mental health is more vulnerable to SO_2 pollution than men's. However, the regression coefficient of the interaction between SO_2 and gender is 0.0173, which indicates that SO_2 has a positive impact on the gender effect of depression. **Table 3** shows that under low SO_2, the average depression of men is 2.2850 lower than that of women, while under high SO_2, the average depression of men is 1.8871 lower than that of women. It can be seen clearly from **Fig 1**(a) that the inclination degree of the blue line (low SO_2) is greater than that of the red line (high SO_2). Namely, under high SO_2, the difference in depression between men and women decreases. This is consistent with the results of Zhang et al, which indicate that when men and women face the same level of pollution exposure, men are more susceptible (Zhang, Jin et al. 2018).

For education, the regression coefficient is -0.1527, which indicates that the higher an individual's education level is, the lower the degree of depression. Moreover, the degree of depression decreased by 0.1527 for each unit increase in education level. The regression coefficient of the interaction between SO_2 and education level is -0.0030, which indicates that SO_2 concentration has a negative impact on the depression inequality caused by the individual education level gap. **Table 3** shows that under low SO_2, depression decreases by 0.1796 for each unit increase in education level. However, with high SO_2, depression decreases by 0.2487 for each unit increase in education level. **Fig 1**(b) also clearly shows that the inclination degree of the red line (high SO_2) is greater than that of the blue line (low SO_2); that is, the individual depression inequality caused by the gap in education level is further strengthened in areas with high SO_2. This is because people with a higher education level have stronger ability to learn and master

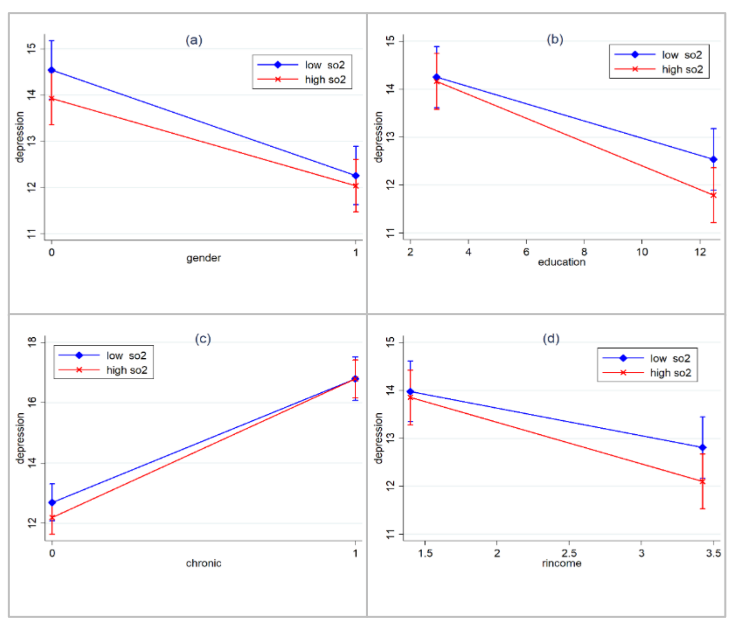

Fig 1 Inequality of depression under high and low SO_2

pollution avoidance knowledge and strategies and have a stronger preference for good environmental quality (Qi and Lu, 2015).

Table 2 Three-level model results.

Level	Variable	Coefficient	Interactive impact	Coefficient	Interactive impact	Coefficient
Individual	Gender	-2.3998***	SO_2#gender	0.0173*	med#gender	-9.84E-06*
	Edu	-0.1527***	SO_2#edu	-0.0030 **	med#edu	5.88E-07
	Social	-0.7230***	SO_2#social	-0.0020	med#social	-4.60E-06*
	Urban	-1.3960***	SO_2#urban	0.0189	med#urban	-7.06E-06
	Chronic	3.7834***	SO_2#chronic	0.0218*	med#chronic	1.61E-05**
	Rincome	-0.4505***	SO_2#rincome	-0.0125**		
	Age	-0.0047	SO_2#med	8.75E-07**		
	Smoke	0.4292***				
Family	Med	1.61E-05				
	Fincome	-9.30E-07*				
	Fsize	-0.3333***				
Province	SO_2	0.0138				
	perGDP	-3.16E-05***				

Table 3 The marginal effect of individual depression.

Variable	Coefficient	
	low SO_2	high SO_2
Gender	-2.2850*** (0.1848)	-1.8872*** (0.1522)
Education level	-0.1796*** (0.0223)	-0.2487*** (0.0187)
Chronic disease	4.1035*** (0.2423)	4.6043*** (0.1885)
Relative income	-0.5774*** (0.1002)	-0.8653*** (0.0782)

Note: ***, **, and * are significant at the 1%, 5% and 10% levels, respectively.

In terms of chronic disease, the average depression of individuals with chronic diseases was 3.7834 higher than that of individuals without chronic diseases. The regression coefficient of the interaction between SO_2 and chronic diseases is 0.0218, which indicates that SO_2 has a positive impact on the depression inequality caused by chronic diseases. **Table 3** shows that the average depression of individuals with chronic diseases is 4.1035 lower than that of individuals without chronic diseases under low SO_2. However, under high SO_2, the average depression of the individuals with chronic disease is 4.6043 lower than that of individuals without chronic disease. **Fig 1**(c) also shows that the inclination degree of the red line (high SO_2) is greater than that of the blue line (low SO_2), which indicates that the higher the SO_2 concentration is, the greater the difference in depression between individuals with and without chronic disease and nonchronic disease individuals. This is consistent with the finding of a large number of studies that air pollution can seriously affect the physical health of individuals, thus further aggravating the degree of depression (Spitzer et al., 2011).

The regression coefficient of individual relative income is - 0.4505, which indicates that the higher the relative income is, the lower the degree of psychological depression. For each unit increase in relative income, an individual's depression decreases by 0.4505. The regression coefficient of the interaction between SO_2 and relative income level is -0.0125, which indicates that SO_2 has a negative impact on the depression inequality caused by the relative income gap between individuals. **Table 3** shows that under low SO_2 concentration, depression is reduced by 0.5774 for each unit increase in an individual's relative income. However, under high SO_2 concentration, depression decreases by 0.8653 for each unit increase in an individual's relative income. **Fig 1**(d) shows that the inclination degree of the red line (high SO_2) is greater than that of the blue line (low SO_2), which indicates that the higher the SO_2 concentration is, the more serious the depression inequality caused by the relative income gap. This is because, compared with low-income individuals, middle- and high-income individuals pay more attention to pollution and have stronger economic ability to avoid the associated health risks (Qi and Lu, 2015).

2.4 Conclusions

There are significant differences in the degree of depression among different individuals, of which 28.73% and 1.91% are caused by family and province-level differences. Differences in family health care expenditure and province-level SO_2 concentration are important reasons for individual differences in depression.

At individual level, there are gender differences in the degree of depression, and the mental health of men is better than that of women. Individuals with high social and economic status have better mental health than individuals with low social and economic status. In addition, living habits, such as smoking, and physical health conditions, such as chronic diseases, can aggravate depression.

At family level, family health care expenditure has a significant regulatory effect on depression inequality caused by gender differences, social status gaps and physical health status gaps. The higher the family health care expenditure is, the greater the depression inequality caused by gender differences, social status differences and physical health differences.

At province level, the influence of individual characteristics on depression varies with SO_2 concentration in different areas. The average depression score of men was 2.3998 lower than that of women, but the difference in depression between men and women was smaller under high SO_2 concentration. The higher the education level was, the lower the depression score. The depression inequality caused by educational level disparity increased with the increase in SO_2 concentration. The average depression score of individuals with chronic diseases was 3.7834 higher than that of individuals without chronic diseases. Moreover, the difference in depression between individuals with chronic diseases and without chronic diseases was larger under high SO_2 concentration. Relative income had a negative impact on depression score. The depression inequality caused by relative income disparity increased with the increase in SO_2 concentration.

ACKNOWLEDGEMENT

This paper is greatly supported by the National Natural Science Foundation of China (Grant No. 71991481 and No.71991480).

REFERENCE

[1] Cai S, Wang Y, Zhao B, Wang S, Chang X, Hao J. The impact of the "air pollution prevention and control action plan" on PM2.5 concentrations in Jing-Jin-Ji region during 2012-2020. Science of the Total Environment 2017; 580: 197-209.

[2] Li WB, and Zou P. Air Pollution and Residents' Mental Health-An Estimation based on Regression Discontinuity. Journal of Beijing Institute of Technology (Social Sciences Edition) 2019; 21(6): 10-21. (In Chinese)

[3] Qi Y, and Lu HY. Pollution, health and inequality-overcoming the trap of "environmental health poverty". Management World 2015; 9: 32-51. (In Chinese)

[4] Ren T, Yu X, Yang WW. Do cognitive and non-cognitive abilities mediate the relationship between air pollution exposure and mental health? Plos One 2019; 14(10): e0223353.

[5] Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. Psycholodical Bulletin 1979; 86(2): 420-428.

[6] Spitzer C, Sven G, Grabe HJ, et al. Mental health problems, obstructive lung disease and lung function: findings from the general population. Journal of Psychosomatic Research 2011; 71 (3):174-179.

[7] World Health Organization. 2017. Depression and other common mental disorders: global health estimates. World Health Organization. Available from: http://www.who.int/iris/handle/10665/254610.

[8] World Health Organization. 2005. WHO air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulphur dioxide. Global update 2005. Available from: https://www.eea.europa.eu/data-and-maps/indicators/exceedance-of-air-quality-limit/who-air-quality-guidelines-for.

[9] Zhang YJ, Jin YL, Zhu TT. The health effects of individual characteristics and environmental factors in China: Evidence from the hierarchical linear model. Journal of Cleaner Production 2018; 194: 554-563.

[10] Zivin JG, and Neidell M. Environment, health, and human capital. Journal of Economic Literature 2013; 51(3): 689–730.