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ABSTRACT

The Effects of Exposure to Air Pollution on Subjective Well-being in China

This paper studies the impact of six main air pollutants on three key dimensions of subjective well-being (SWB) – life satisfaction, hedonic happiness and mental health. We match a nationally representative survey in China with local air quality and rich weather conditions according to the exact date and county of each interview. By making use of variations in exposures to air pollution across similar respondents living in the same county, we find that PM2.5 reduces hedonic happiness and increases the rate of depressive symptoms, but does not affect life satisfaction. Our results show that the benefits of reducing air pollution would be higher if the hidden costs of air pollution on SWB in China are taken into account.

JEL Classification: I31, Q51, Q53

Keywords: life satisfaction, hedonic happiness, depressive symptoms, air pollution, China

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1. **Introduction**

There has been a burgeoning body of studies examining the impact of exposure to air pollution on a wide range of health measures in China, especially diseases and mortality (e.g. Alberini and Krupnick 1998; Chen et al. 2013; Tanaka 2015; He, Fan, and Zhou 2016). Health includes not only physical health and absence of diseases but also mental health [1]. Subjective well-being (SWB) plays an important role in maintaining physical health (National Research Council and Institute of Medicine 2009). SWB has been listed as an important component in policy making in more and more countries (Levinson 2013). However, the link between air pollution and SWB, such as happiness and mental health, has not been well studied in China compared to the link with physical health until recently.

In responding to severe air pollution in some developing countries, a few studies have directly tested the link between air pollution and key psychological outcomes, including mental health and happiness. For instance, Li, Folmer and Xue (2014) show that both intensity of exposure to polluted air and hazard of pollutants affect people's happiness in mining areas in China. Using a nationally representative sample, Zhang, Zhang and Chen (2017a) find salient negative effect of fine particulates on hedonic happiness.

However, these studies focus only on hedonic happiness, but ignore evaluative measures of happiness. Both measures have been used in the SWB literature (Kahneman and Deaton 2010; Deaton and Stone 2013). Hedonic happiness refers to moment-to-moment experienced utility and directly links to immediate emotions and affection. Evaluative happiness, such as life satisfaction, reflecting an overall assessment of the entire life, is less likely subject to short-term changes in the external environment, such as daily air pollution. The time window of measuring mental health sits between evaluative and hedonic happiness. Therefore, the effect of air pollution on mental health tends to be smaller than the effect on hedonic happiness but larger than that on life satisfaction. Zhang, Zhang and Chen (2017b) for the first time compare the effect of air pollution on various SWB measures by using Chinese longitudinal data to remove individual heterogeneity in the reporting of SWB. Following Zhang, Zhang and Chen (2017b), this chapter simultaneously estimates the effects of specific air pollutants on three key measures of SWB.

However, due to the lack of air pollutant data, Zhang, Zhang and Chen (2017b) use only an Air Pollution Index (API), a comprehensive index for air pollution. API has a shortcoming in that it doesn't reveal specific air pollutant concentrations,[2] although different pollutants may affect SWB through different channels. Investigating differential effects of air pollutants on SWB may help us understand which channels work and which do not. This improved knowledge could in turn guide evidence-based policy making to mitigate specific sources of pollutants.

Studies have shown that finer particulate matter, such as that with a diameter smaller than 2.5 micrometers (PM2.5), tends to be more detrimental to health than larger particulates, such as PM10 (Cao et al. 2014; Pal et al. 2016). PM10 is usually trapped in the upper airways and can be cleared by mucociliary mechanisms. However, due to its miniature size, PM2.5 can penetrate lungs at the alveolar level, translocate directly through the alveolar capillaries into the circulatory system, and leave toxic substances in the blood, causing cumulative damage to the body (Stanek et al. 2011). Ozone (O_3) can react with body molecules to create toxins, causing asthma and respiratory problems (Sanders 2012). High levels of O_3 and sulfur dioxide (SO_2) are found to cause psychiatric distress (Rotton and Frey 1984). Carbon monoxide (CO) prevents the body from releasing adequate oxygen to vital organs, in particular to the brain, which consume a large fraction of total oxygen intake. High concentrations of CO and nitrogen dioxide (NO_2) are significantly associated with headache, eye irritation, and respiratory problems (Nattero and Enrico 1996). In this chapter, we examine the impact of six main pollutants — PM2.5, PM10, NO_2, SO_2, CO, and ozone.

We merge a nationally representative survey – the China Family Panel Studies (CFPS) – with newly released daily air quality data that contain rich information on six main pollutants and weather conditions at the time and county of each interview. A key assumption for our identification strategy is that day-to-day fluctuations of air quality in a given county have little to do with the characteristics of individual respondents.

More generally, under the assumption that locational sorting in response to air pollution occurs more slowly than changes in SWB caused by transitory air pollution, pollution is literally random to survey subjects.[3]

We find that PM2.5 significantly reduces hedonic happiness and raises the rate of depressive symptoms, while PM10 only marginally lowers hedonic happiness. Both PM2.5 and PM10 have little effect on life satisfaction. Other pollutants impose negligible effects on SWB measures.

Given that air pollution is ubiquitous in many developing countries such as Bangladesh, India and Nepal, our study on China can shed some light for other developing countries as well.[4]

The rest of the chapter is organized as follows. Section 2 describes the data. Section 3 lays out the empirical strategy. Section 4 presents our main findings, including robustness checks and heterogeneous tests. Finally, section 5 concludes.

2. Data

2.1. Subjective Well-being Measures

Our SWB measures come from the China Family Panel Studies (CFPS), a nationally representative survey of Chinese communities, families, and individuals. The CFPS is carried out by the Institute of Social Science Survey of Peking University. There are three advantages of the CFPS for our purposes. First, rich measures ranging from long-term life satisfaction to moment-to-moment hedonic happiness allow us to compare the effects of air pollution in various time frames. Second, information about geographic locations and dates of interviews for all respondents enables us to precisely match individual SWB measures in the survey with external air quality data. Third, the survey collected rich information at multiple levels, allowing us to control for a wide range of covariates.

We make use of three types of SWB measures in the third wave of the CFPS survey conducted in year 2014. The first is life satisfaction. The CFPS asked each respondent to answer the question, “Overall, how satisfied are you with your life?” on a scale from 1 (*not satisfied at all*) to 5 (*very satisfied*). With no specified time frame, life satisfaction, an evaluative measure of SWB, reflects the extent to which people’s own experiences match their long-term aspirations and expectations about their lives as a whole (Stone and Mackie 2014). Life circumstances, such as income, education, and social status, are among the main determinants of life satisfaction.

The second SWB measure comes from the 6-item Kessler Psychological Distress Scale (K6) developed by Kessler et al. (2003), a self-reported scale designed to measure the current level of depressive symptomatology in the general population. Each item in the K6 scores from 0 (*never*) to 4 (*almost every day*) with a total score ranging from 0 to 24. We create a binary indicator to define depressive symptoms as those with total K6 scores no less than 4. Compared to life satisfaction, the K6 highlights multidimensional emotional experiences that affect people in a shorter period.

The third SWB measure gauges short-term hedonic happiness. The first item in the K6 asks respondents to what extent they felt hard to cheer up in the past month, ranging from 0 (*almost every day*) to 4 (*never*). The higher the number, the happier the respondents are. Compared to evaluative well-being, depression symptoms and hedonic happiness belong to hedonic well-being and are more directly related to the environment as well as people’s affective state in day-to-day and moment-to-moment life (Stone and Mackie 2014).[5]

2.2. Interpolation of Air Pollution and Weather Measures

We obtain air pollution measures from the daily air quality report published by the Ministry of Environmental Protection of China (MEP). The report started to publish daily concentrations of six pollutants, including PM2.5, PM10, carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3) and sulfur dioxide (SO_2) in 2014. The dataset we use in our analysis covers 947 monitoring stations along with longitude and altitude information for each station. Figure 14A.1 and Figure 14A.2 indicate that particulate matters (PM2.5 and PM10) are highly concentrated and are dominant sources of air pollution on most days in China.

We also include rich weather data in our analysis to help isolate the impact of air pollution from other weather patterns. The weather data come from the National Climatic Data Center under the US National Oceanic and Atmospheric Administration. The dataset contains daily records of temperature, precipitation, wind speed, and an indicator for bad weather[6] from 402 monitoring stations in China. Sunshine duration is obtained from the 194 monitoring stations of China National Meteorological Information Center. Sunshine may affect individuals' moods, social behavior, and health (Cunningham 1979; Wolfson 2013).

To merge the CFPS sample with the air pollution readings, we calculate the weighted average values of all the monitoring stations within 60 km to the centroids of each CFPS county, where the weights are equal to the inverse of distance between stations and the county centroids. In the absence of stations within this radius, we obtain air quality from the nearest station within 100 kilometers. Weather controls are matched in the same way.[7] The binary indicator for bad weather and the sunshine duration are obtained from the nearest monitoring station regardless of the distance.

The 2014 wave of CFPS has 31,832 individuals, of which 22,896 could be matched to air quality and weather data within 100 kilometers.[8] Due to 21 missing values for life satisfaction, 51 missing values for hedonic happiness, 105 missing values for depressive symptoms, and 1,256 missing values for household demographics, the final dataset for analyses includes 21,619 observations for life satisfaction, 21,589 observations for hedonic happiness, and 21,535 observations for depressive symptoms.[9]

3. Empirical Strategy

Our baseline econometric specification is as follows:

$$H_{ijt} = \alpha P_{jt} + \beta \ln Y_{ijt} + X'_{ijt} r + W'_{jt} \phi + \delta_j + \eta_t + \varepsilon_{ijt} \quad (1)$$

The dependent variable H_{ijt} is the SWB measure of respondent i in county j at date t. The key variable P_{jt} is the concentrations of air pollutants in county j at date t, the day of the interview. $\ln Y_{ijt}$ is the log form of household per capita income. We control for a set of demographic covariates X_{ijt}, including age and its squared term, gender, marital status, years of education, unemployment status, party membership, and health status. W_{jt} indicates a vector of rich weather conditions on the day of the interview, to mitigate the concern that they are correlated with both SWB and air quality and therefore might bias our estimations. δ_j represents county fixed effect; η_t indicates month and day-of-week fixed effects. ε_{ijt} is the error term. Standard errors are clustered at the county level. Table 14.1 describes key variables and their summary statistics.

[Insert Table 14.1]

Figure 14A.3 shows the distribution of interview months in our final sample, ranging between July and December 2014. Most surveys were conducted in July and August during which college students in summer break were recruited as numerators for the surveys. Our identification makes use of variations in exposure to air pollution across similar respondents living in the same county in the same year. There is substantial within-county variation in air quality during the more than four months survey in most counties.[10]

4. Results

4.1. Baseline Results

We report the baseline results of air pollution on various SWB measures in Table 14.2 through Table 14.4, respectively. In each table, Columns (1) through (6) estimate Equation (1) respectively using PM2.5, PM10, CO, NO_2, O_3 and SO_2 as the air pollution measures.

Table 14.2 presents the baseline results on life satisfaction. Column (1) begins with PM2.5. We do not find any significant relationship between PM2.5 and life satisfaction. Household per capita income is positively correlated with life satisfaction. Consistent with the happiness literature, there is a U-shaped relationship between age and life satisfaction with the lowest level being around age 45. Unemployed people who are in poor health or divorced report lower life satisfaction. Party membership is associated with a higher degree of life satisfaction. Similar to the results on PM2.5, there are not strong correlations between other air pollutants and life satisfaction.

[Insert Table 14.2]

Table 14.3 reports the estimates for hedonic happiness. Column (1) shows that hedonic happiness decreases with PM2.5 on the day of interview. The effects are significant at the 5% level. A 1 μg/m^3 increase in PM2.5 leads to a decline in happiness by 0.565‰. Household income is positive associated with hedonic happiness. A 1% increase in household per capita income raises happiness by 0.15‰. Therefore, in order to keep their happiness constant, people are on average willing to pay 3.8% of their annual income for a 1 μg/m^3 reduction in PM2.5 on the day of the interview. To put this into context, note that one standard deviation (hereafter SD) of PM2.5 is 33.260 μg/m^3. A one SD increase in PM2.5 results in a decline in happiness by 1.879% (=33.260×0.565‰). Married, more educated, and healthier men tend to be happier.

[Insert Table 14.3]

Column (2) of Table 14.3 identifies the impact of PM10 on hedonic happiness. A one SD increase in PM10 is statistically significantly associated with a decline in happiness by 1.635% (=46.721×0.350‰), a little smaller than PM2.5. The different estimates between PM2.5 and PM10 suggest that people are more sensitive to finer particulates (PM2.5) than coarse particulates (PM10). Considering that the related literature in China has largely focused on coarse particulates, this finding highlights the importance of giving more attention to finer particulates.

Column (3) presents results for CO. The coefficient on CO is statistically insignificant and much smaller than PM2.5 in magnitude. The difference may stem from the fact that CO is only a dominant source of air pollution for 2% of days (Figure 14A.2). Besides, CO is odorless, colorless and thus less noticeable.

Column (5) estimates the effects of NO_2 on hedonic happiness. The marginal effect of NO_2 is about half of the size of PM2.5 with no significance. The National Ambient Air Quality Standards (NAAQS) of the United States Environmental Protection Agency (EPA) stipulates that the cutoff value for NO_2 is 53 ppb (100 μg/m^3). The mean and SD in our sample are both within this safety range, thus NO_2 is a minor pollutant in China.

Similarly, the coefficient on ozone presented in Column (5) is statistically insignificant and the size is basically the same as NO_2. Ozone is a dominant pollutant in more than 10% of days a year (Figure 14A.2), but its concentration in our sample may only trigger discomfort among vulnerable people, such as those with lung diseases.[11]

The last column reports results for SO_2. Several papers examine the effects of annual average SO_2 on life satisfaction (Luechinger 2009; Luechinger 2010; Ferreira et al. 2013). In our case, the coefficient on SO_2 is still statistically insignificant.

Table 14.4 reports the effects of air pollution on depressive symptoms. Column (1) shows that depressive symptoms are positively correlated with PM2.5. A one SD increase in PM2.5 corresponds to an increase in the probability of having depressive symptoms by 7.450 (=33.260×0.224) percentage points. However, as presented in Column (2), PM10 does not appear to be related to depressive symptoms. By comparison, PM2.5 is a much stronger risk factor for depressive symptoms than PM10. Consistent with hedonic happiness, we do not find any significant effects of other air pollutants, including CO, NO_2, ozone and SO_2, on depressive symptoms.

[Insert Table 14.4]

4.2. Robustness Checks

In Table 14.5, we perform a set of alternative specifications to check the robustness of our main results. We focus on PM2.5 because it is associated with more detrimental health effects as shown in the baseline. Panels A, B, and C present results for life satisfaction, hedonic happiness and depressive symptoms, respectively.

[Insert Table 14.5]

Column (1) replicates the baseline results in Columns (1) of Table 14.2 through Table 14.4 for ease comparison. Column (2) adds a control variable, the PM2.5 level on the day prior to the interview date, to account for the lagged effect of pollution. After its inclusion, the negative effect of contemporaneous PM2.5 on hedonic happiness and mental well-being amplifies. However, the effect on life satisfaction remains insignificant.

Since the K6 scale asks for people's feelings in the past month, we use average local PM2.5 in the past 30 days instead of contemporaneous PM2.5 level to examine the long-term effects of air pollution on SWB. As reported in Column (3), there is no significant relationship between longer term air pollution and SWB, suggesting that people care more about their current exposure. There is another possibility that daily PM2.5 on the date of the interview reflects average pollution in a county over a longer period, such as one month. To mitigate this concern, Column (4) adds monthly mean PM2.5. The coefficient for monthly PM2.5 level is insignificant, while daily PM2.5 remains significant and essentially the same magnitude, confirming that day-to-day fluctuations in air quality drive our results.

Column (5) estimates equation (1) using an ordered probit model.[12] In Panel A, the coefficient on PM2.5 remains insignificant for life satisfaction. As shown in Panel B and Panel C, PM2.5 is negatively correlated with hedonic happiness and depressive symptoms with statistical significance level at 5% or higher. Overall, our baseline results are robust to several alternative specifications.

4.3. Heterogeneous Effects

This section examines the heterogeneous effects of air pollution on hedonic well-being. First, we check whether the effect varies by age or not. Columns (1) through (5) in Panel A and Panel B of Table 14.6 present the impact of air pollution by gender and age cohort, respectively. Results suggest that men respond more strongly to air pollution than women. Interestingly, age differences vary with the choice of outcome variables. Specifically, young people are more sensitive to air pollution in hedonic happiness, while mental health among the elderly is more saliently affected.

[Insert Table 14.6]

Second, we examine the heterogeneity by education level. It has been shown in some literature that more education may enable one to acquire and digest information about air quality and become more concerned (Levinson 2012; Greenstone and Hanna 2014; Li, Folmer and Xue 2014). As revealed in Columns (1) through (2) of Panel C and Panel D, people who finished at least six years of education are indeed more affected in terms of hedonic happiness than those less educated.

Third, we check if the effect differs by pollution level. People living in more polluted areas could be more (or less) sensitive to pollution than those in less polluted areas. The net effect may rely on which force dominates, dose-response relationship or habituation/self-selection. Columns (3) and (4) of Panels C and D report the regression results for two subsamples according to the median level of yearly mean PM2.5. Apparently, the effects of air pollution are more salient in highly polluted areas, indicating that the dose-response relationship may dominate.

Finally, families with small children may be more concerned about bad air quality. We divide the sample according to whether or not a family has a child younger than age six. As revealed in Columns (5) and (6) of Panels C and D, families with young children are marginally more vulnerable to air pollution in terms of both hedonic happiness and depressive symptoms.

5. Conclusion

This paper estimates the impact of six air pollutants on long-term life satisfaction, short-term hedonic happiness, and depressive symptoms by matching various self-reported SWB measures in CFPS, a nationally representative survey, with daily air quality data according to the exact date and county of each interview. PM2.5 and PM10 are found to be negatively associated with hedonic happiness. For depressive symptoms, only PM2.5 matters. Other pollutants are not correlated with any of the three SWB measures. We also find some heterogenous effects. People who receive more education, reside in more polluted areas, or have young children are more sensitive to air pollution in terms of hedonic happiness.

Our results have important policy implications. China has been making real progress in striving for cleaner air according to its national plan 2016-2020.[13] The optimal environmental regulations depend on the cost-benefit tradeoffs. Our findings indicate that the currently estimated costs of pollution may understate some important social costs. If counting them in, the benefits of reducing pollution would be higher. Many other developing countries also face serious air pollution problem, the lessons learned from China can shed light on these countries as well.

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[1] http://www.who.int/about/mission/.

[2] API is generated by a piecewise linear transformation from the concentrations of air pollutants, including sulfur dioxide (SO2), nitrogen dioxide (NO2), and fine particulate matter smaller than 10 micrometers (PM10).

[3] Several studies have made such assumption in their analyses, e.g. Levinson (2012) and Currie et al. (2014) provide an excellent review of this approach.

[4] According to the 2016 Environmental Performance Index published by the Yale University, the world's top five most air polluted countries are Bangladesh, China, India, Nepal and Laos.

[5] Hedonic well-being is closely related to the often-used terms "experienced well-being" and "emotional well-being." They are often used interchangeably in the literature.

[6] Bad weather includes fog, rain/drizzle, snow/ice pellets, hail, thunder, and tornadoes/funnel clouds.

[7] We use the same interpolation approach as Zhang, Zhang and Chen (2017a). The median matching distance is 33 km. PM2.5 particles are light and can stay in the atmosphere for 3-4 days. They can be transported by wind for more than 100 km (Barwick et al. 2017). Our baseline results are robust to matching using narrower radiuses, but the current set of results is reported to retain more observations in the analysis. Meanwhile, these baseline results are robust to alternative weights, including inverse of the square root distance or squared distance between the monitoring stations and the county centroids.

[8] Counties unmatched to any air quality or weather monitoring station within 100 kilometers are dropped. The matching rate 71.9% (=22,896/31,832) is within a reasonable range. For example, a highly comparable study, Levinson (2012), retained 52.3% of the observations when matching the U.S. General Social Survey with PM10 readings from the EPA's Air Quality System.

[9] We use different sets of individuals for the three SWB measures to retain more observations in the analysis. Our results are robust to restricting the sample to the same set of individuals across regressions.

[10] Although most interviews were conducted in summer, the interview period often lasted for more than four months in each county, sometimes extended to November and December, when air quality is generally worse.

[11] Source: https://www3.epa.gov/airnow/aqi-technical-assistance-document-dec2013.pdf.

[12] For depressive symptoms, we simply run a probit model.

[13] The national plan stipulates that air quality of cities at and above the prefectural level must be good or excellent for 80 percent of days each year. Please refer to http://language.chinadaily.com.cn/2016-03/18/content_23944369_2.htm.

References

Alberini, A. and A. Krupnick (1998), ‘Air quality and episodes of acute respiratory illness in Taiwan cities: Evidence from survey data’, *Journal of Urban Economics*, 44, 68-92.

Barwick, P. J., S. Li, D. Rao and N. B. Zahur (2017), ‘Air pollution, health spending and willingness to pay for clean air in China’, working paper.

Byers, A. L., K. Yaffe, K. E. Covinsky, M. B. Friedman and M. L. Bruce, (2010), ‘High occurrence of mood and anxiety disorders among older adults: The National Comorbidity Survey replication’, *Arch Gen Psychiatry*, 67, 489-96.

Cao, C., W. Jiang, B. Wang, J. Fang, J. Lang, G. Tian, J. Jiang and T. F. Zhu (2014), ‘Inhalable microorganisms in Beijing’s PM2.5 and PM10 pollutants during a severe smog event’, *Environmental Science & Technology*, 48, 1499-1507.

Chen, Y., A. Ebenstein, M. Greenstone, and H. Li (2013), ‘Evidence on the impact of sustained exposure to air pollution on life expectancy from China’s Huai River policy’, *PNAS* 110, 12936–12941.

Cunningham, M. R (1979), ‘Weather, mood, and helping behavior: Quasi-experiments with the sunshine samaritan’, *Journal of Personality and Social Psychology*, 37 (11), 1947–1956.

Currie, J., Graff Zivin, J., Mullins, J., and M. Neidell (2014), ‘What do we know about short- and long-term effects of early-life exposure to pollution’, *Annual Review of Resource Economics*, 6(1), 217-247.

Deaton, A. and A. A. Stone (2013), ‘Two happiness puzzles’, *American Economic Review*, 103, 591–597.

Ferreira, S., A. Akay, F. Brereton, J. Cuñado, P. Martinsson, M. Moro and T. F. Ningal (2013), ‘Life satisfaction and air quality in Europe’, *Ecological Economics*, 88, 1-10.

Greenstone, M., and R. Hanna (2014), ‘Environmental regulations, air and water pollution, and infant mortality in India’, *American Economic Review*, 104 (10), 3038–3072.

He, G. and M. Fan and M. Zhou (2016), ‘The effect of air pollution on mortality in China: Evidence from the 2008 Beijing Olympic Games’, *Journal of Environmental Economics and Management*, 79, 18-39.

He, J., H. Liu and A. Salvo (2016), ‘Severe air pollution and labor productivity: Evidence from industrial towns in China’, IZA Discussion Paper 8916.

Kahneman, D., and A. Deaton (2010), ‘High income improves evaluation of life but not emotional well-being’, *PNAS*, 107, 16489–16493.

Kessler R. C., P.R. Barker, L.J. Colpe, J.F. Epstein, J.C. Gfroerer, E. Hiripi, M.J. Howes, S.T. Normand, R.W. Manderscheid, E.E. Walters, A.M. Zaslavsky (2003), ‘Screening for serious mental illness in the general population', *Arch Gen Psychiatry*, 60(2), 184–189.

Levinson, A. (2012), 'Valuing public goods using happiness data: The case of air quality', *Journal of Public Economics*, 96, 869–880.

Levinson, A. (2013), 'Happiness, behavioral economics, and public policy', NBER Working Papers 19329.

Li, Z., H. Folmer and J. Xue (2014), 'To what extent does air pollution affect happiness? The case of the Jinchuan mining area, China', *Ecological Economics*, 99, 88-99.

Luechinger, S. (2009), 'Valuing air quality using the life satisfaction approach', *Economic Journal*, 119, 482–515.

Luechinger, S. (2010), 'Life satisfaction and transboundary air pollution', *Economics Letters*, 107, 4–6.

National Research Council and Institute of Medicine (2009), *Preventing Mental, Emotional, and Behavioral Disorders Among Young People: Progress and Possibilities*, Washington, DC: The National Academies Press.

Nattero, G., and A. Enrico (1996), 'Outdoor pollution and headache', *Headache*, 36, 243–245.

Pal, C., J. Bengtsson-Palme, E. Kristiansson and D. G. Joakim Larsson, 2016, 'The structure and diversity of human, animal and environmental resistomes', *Microbiome*, 4 (1), 4-54.

Rotton, J. and J. Frey (1984), 'Psychological costs of air pollution: Atmospheric conditions, seasonal trends, and psychiatric emergencies', *Population and Environment*, 7(1), 3–16.

Sanders, N. J. (2012), 'What doesn't kill you makes you weaker: Prenatal pollution exposure and educational outcomes', *Journal of Human Resources*, 47, 826–850.

Stanek, L.W., J.S. Brown, J. Stanek, J. Gift and D.L. Costa (2011), 'Air pollution toxicology--A brief review of the role of the science in shaping the current understanding of air pollution health risks', *Toxicological Sciences*, 120(Suppl 1): S8-27.

Stone, A. A., and C. Mackie (ed.) (2014), *Subjective Well-being: Measuring Happiness, Suffering, and Other Dimensions of Experience*, Washington, DC: National Research Council, National Academies Press.

Tanaka, S. (2015), 'Environmental regulations on air pollution in China and their impact on infant mortality', *Journal of Health Economics*, 42, 90-103.

Wolfson, E. (2013), 'Your zodiac sign, your health', *The Atlantic*, November, 15.

Zhang, X., X. Zhang and X. Chen (2017a), 'Valuing air quality using happiness data: The case of China', *Ecological Economics*, 137, 29-36.

Zhang, X., X. Zhang and X. Chen (2017b), ‘Happiness in the air: How does a dirty sky affect mental health and subjective well-being’, *Journal of Environmental Economics and Management*, 85, 81-94.

Table 14.1: Summary statistics of key variables

Variable	Definition	Mean	Std. Dev.
Life satisfaction	life satisfaction, ranging from 1 to 5, the higher the better	3.572	1.156
Hedonic happiness	ranging from 0 to 4, higher numbers represent greater happiness	3.233	0.938
Depressive symptoms	indicator for depressive symptoms (= 1 if K6 total scores ≥ 4)	0.328	0.470
PM2.5	particulate matter with a diameter smaller than 2.5 micrometers ($\mu g/m^3$)	47.858	33.260
PM10	particulate matter with a diameter smaller than 10 micrometers ($\mu g/m^3$)	81.046	46.721
CO	carbon monoxide ($\mu g/m^3$)	1.004×10^3	0.615×10^3
NO_2	nitrogen dioxide ($\mu g/m^3$)	28.940	14.878
O_3	ozone ($\mu g/m^3$)	119.899	59.102
SO_2	sulfur dioxide ($\mu g/m^3$)	22.062	20.619
Household per capita income (log)	household per capita income (Chinese *yuan*)	9.031	1.214
Male	indicator for being male	0.486	0.500
Age (÷10)	age (÷10)	4.660	1.678
Married	indicator for being married	0.797	0.402
Education years	education years	7.480	4.983
Unemployed	indicator for being unemployed	0.012	0.109
Party	indicator for being a Communist Party member	0.077	0.267
Chronic disease	indicator for suffering from chronic diseases	0.170	0.376

Source: China Family Panel Studies 2014.

Table 14.2: Effects of air pollution on life satisfaction

Dependent variable	Pollutant					
Life satisfaction	PM2.5 (μg/m^3)	PM10 (μg/m^3)	CO (μg/m^3)	NO_2 (μg/m^3)	O_3 (μg/m^3)	SO_2 (μg/m^3)
	(1)	(2)	(3)	(4)	(5)	(6)
Pollutant (÷1000)	-0.105	-0.047	8.723×10^{-3}	1.250	0.120	0.421
	(0.409)	(0.313)	(0.016)	(0.768)	(0.178)	(0.784)
Household per capita income (log)	0.037***	0.037***	0.037***	0.037***	0.037***	0.037***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Male	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Age (÷10)	-0.290***	-0.289***	-0.289***	-0.290***	-0.289***	-0.290***
	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)
Age (÷10) squared	0.032***	0.032***	0.032***	0.032***	0.032***	0.032***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Married	0.183***	0.183***	0.183***	0.183***	0.183***	0.183***
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
Years of Education	0.004	0.004	0.004	0.004	0.004	0.004
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Unemployed	-0.348***	-0.348***	-0.347***	-0.347***	-0.348***	-0.348***
	(0.073)	(0.073)	(0.073)	(0.073)	(0.073)	(0.073)
Party	0.126***	0.126***	0.126***	0.126***	0.126***	0.126***
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)
Chronic disease	-0.135***	-0.135***	-0.135***	-0.135***	-0.135***	-0.135***
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
County fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Month, day-of-week fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	21,619	21,619	21,619	21,619	21,619	21,619
Adjusted R-squared	0.185	0.185	0.185	0.185	0.185	0.185

Source: China Family Panel Studies 2014.

Note: The weather controls include sunshine duration, mean temperature and its square, total precipitation, mean wind speed, and a dummy for bad weather. Robust standard errors, clustered at the county level, are presented in parentheses. *10% significance level. **5% significance level. ***1% significance level.

Table 14.3: Effects of air pollution on hedonic happiness

Dependent variable	Pollutant					
Hedonic happiness	PM2.5 (μg/m^3)	PM10 (μg/m^3)	CO (μg/m^3)	NO_2 (μg/m^3)	O_3 (μg/m^3)	SO_2 (μg/m^3)
	(1)	(2)	(3)	(4)	(5)	(6)
Pollutant (÷1000)	-0.565**	-0.350*	-2.836×10^{-3}	-0.256	-0.252	-0.696
	(0.242)	(0.211)	(0.014)	(0.991)	(0.155)	(0.617)
Household per capita income (log)	0.015**	0.015**	0.015**	0.015**	0.014**	0.015**
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Male	0.097***	0.097***	0.097***	0.097***	0.097***	0.097***
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Age (÷10)	-0.011	-0.011	-0.011	-0.011	-0.012	-0.011
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
Age (÷10) squared	0.005**	0.005**	0.005**	0.005**	0.005**	0.005**
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Married	0.059***	0.059***	0.059***	0.059***	0.059***	0.059***
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)
Years of Education	0.006***	0.006***	0.006***	0.006***	0.006***	0.006***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Unemployed	-0.187***	-0.186***	-0.186***	-0.186***	-0.185***	-0.186***
	(0.062)	(0.062)	(0.063)	(0.063)	(0.063)	(0.062)
Party	0.033	0.033	0.033	0.033	0.033	0.033
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Chronic disease	-0.371***	-0.371***	-0.371***	-0.371***	-0.371***	-0.371***
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
County fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Month, day-of-week fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	21,589	21,589	21,589	21,589	21,589	21,589
Adjusted R-squared	0.076	0.076	0.076	0.076	0.076	0.076

Source: China Family Panel Studies 2014.

Note: The weather controls include sunshine duration, mean temperature and its square, total precipitation, mean wind speed, and a dummy for bad weather. Robust standard errors, clustered at the county level, are presented in parentheses. *10% significance level. **5% significance level. ***1% significance level.

Table 14.4: Effects of air pollution on depressive symptoms

Dependent variable	Pollutant					
Depressive symptoms	PM2.5 (μg/m^3)	PM10 (μg/m^3)	CO (μg/m^3)	NO_2 (μg/m^3)	O_3 (μg/m^3)	SO_2 (μg/m^3)
	(1)	(2)	(3)	(4)	(5)	(6)
Pollutant (÷1000)	0.242**	0.146	-0.288×10^{-3}	0.286	0.104	0.262
	(0.121)	(0.103)	(0.007)	(0.397)	(0.087)	(0.286)
Household per capita income (log)	-0.013***	-0.013***	-0.013***	-0.013***	-0.013***	-0.013***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Male	-0.061***	-0.061***	-0.061***	-0.061***	-0.061***	-0.061***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Age (÷10)	0.001	0.001	0.001	0.001	0.002	0.001
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Age (÷10) squared	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Married	-0.061***	-0.061***	-0.061***	-0.061***	-0.061***	-0.061***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Years of Education	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Unemployed	0.090***	0.089***	0.089***	0.089***	0.089***	0.089***
	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)
Party	-0.022*	-0.022*	-0.022*	-0.022*	-0.022*	-0.022*
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Chronic disease	0.171***	0.171***	0.171***	0.171***	0.171***	0.171***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
County fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Month, day-of-week fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	21,535	21,535	21,535	21,535	21,535	21,535
Adjusted R-squared	0.089	0.089	0.089	0.089	0.089	0.089

Source: China Family Panel Studies 2014.

Note: The weather controls include sunshine duration, mean temperature and its square, total precipitation, mean wind speed, and a dummy for bad weather. Robust standard errors, clustered at the county level, are presented in parentheses. *10% significance level. **5% significance level. ***1% significance level.

Table 14.5: Robustness checks

	Baseline	Add lagged PM2.5	Average PM2.5 in the past month		Ordered probit
	(1)	(2)	(3)	(4)	(5)
A. Life satisfaction					
PM2.5 (÷1000)	-0.105	-0.314		-0.179	-0.125
	(0.409)	(0.415)		(0.383)	(0.415)
lagged PM2.5 (÷1000)		0.406			
		(0.376)			
Average PM2.5 in the past month (÷1000)			0.777	0.943	
			(1.514)	(1.456)	
Observations	21,619	21,619	21,619	21,619	21,619
Adjusted R-squared	0.185	0.185	0.185	0.185	0.068#
B. Hedonic happiness					
PM2.5 (÷1000)	-0.565**	-0.695***		-0.550**	-0.887***
	(0.242)	(0.251)		(0.230)	(0.317)
lagged PM2.5 (÷1000)		0.254			
		(0.313)			
Average PM2.5 in the past month (÷1000)			-0.691	-0.182	
			(1.104)	(1.084)	
Observations	21,589	21,589	21,589	21,589	21,589
Adjusted R-squared	0.076	0.076	0.076	0.076	0.044#
C. Depressive symptoms					
PM2.5 (÷1000)	0.242**	0.298**		0.237**	0.729**
	(0.121)	(0.124)		(0.113)	(0.357)
lagged PM2.5 (÷1000)		-0.109			
		(0.139)			
Average PM2.5 in the past month (÷1000)			0.281	0.062	
			(0.613)	(0.610)	
Observations	21,535	21,535	21,535	21,535	21,535
Adjusted R-squared	0.089	0.089	0.089	0.089	0.080#

Source: China Family Panel Studies 2014.

Note: Other covariates and fixed effects are the same as those in Column (1) of Table 14.2. Robust standard errors, clustered at the county level, are presented in parentheses. *10% significance level. **5% significance level. ***1% significance level. # indicates the Pseudo R2.

Table 14.6: Heterogeneous effects of PM2.5

	Age			Gender	
	young	middle	old	male	female
	(1)	(2)	(3)	(4)	(5)
A. Hedonic happiness					
PM2.5 (÷1000)	-0.914**	-0.621	-0.404	-0.824***	-0.295
	(0.400)	(0.408)	(0.373)	(0.307)	(0.321)
Observations	6,247	8,274	7,068	10,496	11,093
Adjusted R-squared	0.062	0.083	0.093	0.068	0.078
B. Depressive symptoms					
PM2.5 (mg/m^3)	0.083	0.178	0.371*	0.360**	0.122
	(0.232)	(0.199)	(0.192)	(0.160)	(0.152)
Observations	6,246	8,264	7,025	10,476	11,059
Adjusted R-squared	0.057	0.102	0.131	0.078	0.087

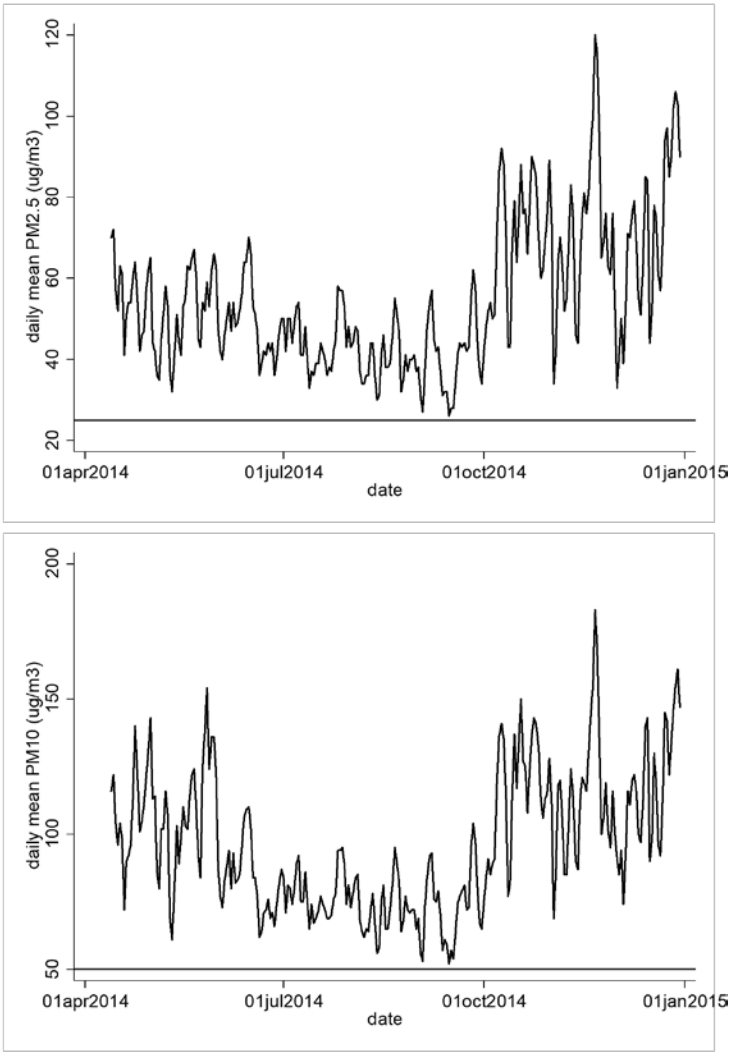
	Education		Pollution level		Children younger than six	
	≤ 6 years	> 6 years	low	high	Yes	No
	(1)	(2)	(3)	(4)	(5)	(6)
C. Hedonic happiness						
PM2.5 (÷1000)	-0.293	-0.712**	-0.616	-0.604**	-1.182*	-0.553**
	(0.366)	(0.301)	(0.482)	(0.276)	(0.674)	(0.244)
Observations	9,577	12,012	10,791	10,798	2,548	18,519
Adjusted R-squared	0.091	0.068	0.071	0.081	0.069	0.080
D. Depressive symptoms						
PM2.5 (÷1000)	0.248	0.208	0.329	0.255*	0.606*	0.182
	(0.195)	(0.152)	(0.256)	(0.133)	(0.352)	(0.119)
Observations	9,536	11,999	10,751	10,784	2,548	18,466
Adjusted R-squared	0.122	0.062	0.099	0.075	0.061	0.097

Source: China Family Panel Studies 2014.

Note: Other covariates and fixed effects are the same as those in Column (1) of Table 14.2. Robust standard errors, clustered at the county level, are presented in parentheses. *10% significance level. **5% significance level. ***1% significance level.

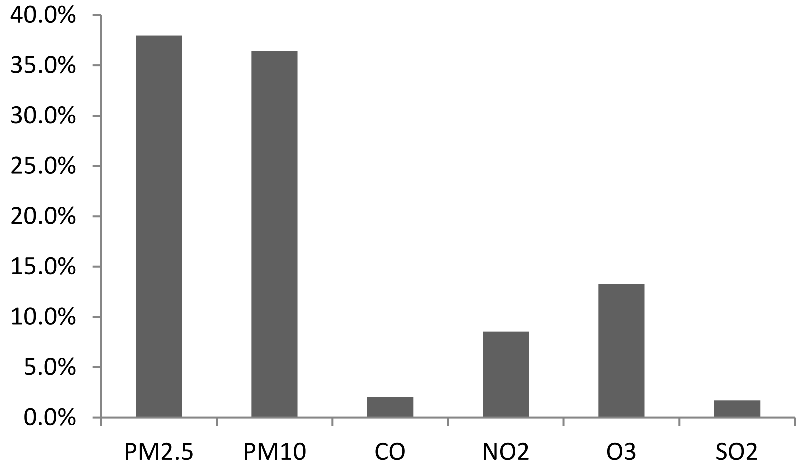
Appendix 14A: Supplementary Figures and Tables

Figure 14A.1: Daily mean PM2.5 and PM10 (µg/m³) in China



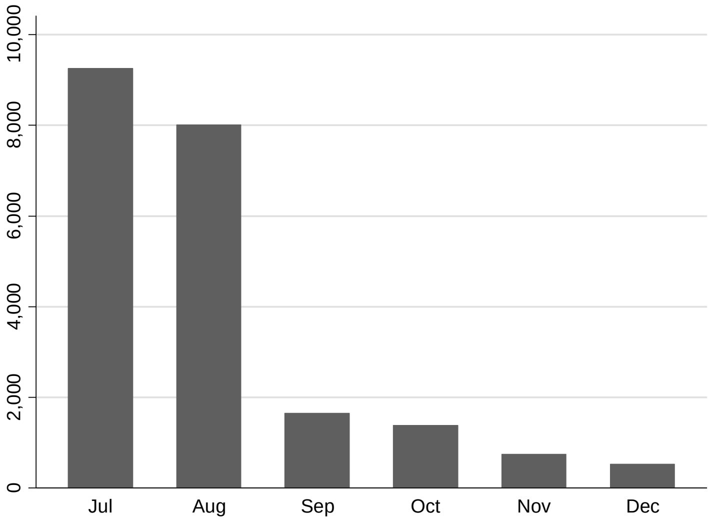
Source: The Ministry of Environmental Protection of the People's Republic of China.
Note: PM2.5 = particulate matter with a diameter smaller than 2.5 micrometers. PM10 = particulate matter with a diameter smaller than 10 micrometers. The standards for 24-hour mean PM2.5 and PM10 published by WHO, plotted as horizontal lines, are 25 µg/m³ and 50 µg/m³, respectively.

Figure 14A.2: Proportion of days each pollutant dominates the air quality index



Source: The Ministry of Environmental Protection of the People’s Republic of China.
Note: CO = carbon monoxide. NO_2 = nitrogen dioxide. O_3 = ozone. PM2.5 = particulate matter with a diameter smaller than 2.5 micrometers. PM10 = particulate matter with a diameter smaller than 10 micrometers. SO_2 = sulfur dioxide.

Figure 14A.3: Distribution of interviews by month in 2014



Source: China Family Panel Studies 2014.
Note: Jul = July. Aug = August. Sep = September. Oct = October. Nov = November. Dec = December.

Appendix 14B: Kessler Psychological Distress Scale (K6) in CFPS 2014

Below is a list of the ways you might have felt or behaved. Please tell me how often you have felt this way during the past month.

0. Never

1. Sometimes

2. Half the Time

3. Often

4. Almost Every Day

During the past month:

1. *I felt so depressed that nothing could cheer me up.*
2. *I felt nervous.*
3. *I felt restless or fidgety.*
4. *I felt hopeless.*
5. *I felt that everything was an effort.*
6. *I felt that life was meaningless.*