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Valuing Air Quality Using Happiness Data: The Case of China

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ABSTRACT

Valuing Air Quality Using Happiness Data: The Case of China[1]

This paper estimates the monetary value of cutting PM2.5, a dominant source of air pollution in China. By matching hedonic happiness in a nationally representative survey with daily air quality data according to exact dates and locations of interviews in China, we are able to estimate the relationship between local concentration of particulate matter and individual happiness. By holding happiness constant, we calculate the tradeoff between the reduction in particulate matter and income, essentially a happiness-based measure of willingness-to-pay for mitigating air pollution. We find that people on average are willing to pay ¥539 ($88, or 3.8% of annual household per capita income) for a 1 μg/m3 reduction in PM2.5 per year per person.

JEL Classification: Q51, Q53, I31

Keywords: willingness to pay, hedonic happiness, air pollution, China

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1. Introduction

Air pollution poses a substantial physical and social threat to human beings.[1] As such, government agencies are often called upon to implement environmental regulations to reduce air pollution. When introducing more stringent regulations, governments need to gauge the monetary value of better air quality so as to compare it with the cost of environmental regulations (Greenstone and Jack 2014). However, because air quality is not a standard good for sale, evaluating its value is a great challenge.

There are three major approaches to valuing air quality: the hedonic approach (Smith and Huang 1995; Chattopadhyay 1999; Chay and Greenstone 2005; Bayer and Timmins 2009; Yusuf and Resosudarmo 2009), the contingent valuation method (CVM) (Alberini and Krupnick 1998; Kwak, Yoo and Kim 2001; Zhai and Suzuki 2008; Vasquez et al. 2009; Wang, Xie and Li 2010; Wang et al. 2013), and the happiness approach.

Each method is associated with its own advantages and disadvantages. The hedonic approach infers the value of air quality from the differences in property values across regions with varying air quality after controlling for many observable factors. The main problem with this approach is location sorting: those who are more concerned about air pollution may move into less polluted areas in the first place, rendering the locational choice endogenous and causing biased estimates on the value of air quality.

The CVM directly surveys people regarding their willingness to pay for better air quality. However, this approach is subject to strategic responses, the ways of questions being framed, and the initial hypothetical monetary value adopted to start the survey. Consequently, estimates based on CVM often yield a wide range of willingness to pay for better air quality. For example, in China, the estimates of

[1] For example, cognitive test scores (Bharadwaj et al. 2014; Ham et al. 2014; Marcotte 2016), human capital formation (Lavy et al. 2014a, 2014b), productivity of indoor workers (Chang et al. 2014; Li, Liu and Salvo 2015), mental health and subjective well-being (Zhang, Zhang and Chen 2015).

willingness to pay for smog mitigation range from ¥428 (Wang et al. 2015) to as large as ¥1,590 per year (Sun, Yuan and Yao 2016).

The happiness approach computes willingness to pay based on average marginal rate of substitution between air pollution and annual income, holding happiness constant in regressions of happiness (stated well-being) on air quality. Since this approach relies on surveys evaluating peoples' stated well-being and does not directly ask about their valuations on public goods per se, strategic responses are largely avoided. In addition, this approach, often based on large representative surveys, can be used to assess heterogeneities in valuations across different subgroups.[2]

There is a burgeoning body of studies valuing air quality based on the happiness approach. However, most studies rely on aggregated air quality data spanning a rather long period, such as one year (Welsch 2006; Luechinger 2009, 2010; Menz and Welsch 2010; Menz 2011; Chen and Shi 2013; Ambrey 2014). Consequently, the aggregated long-term air pollution used in analyses may not reflect the actual exposure at the time of interview faced by survey subjects, resulting in measurement errors.

Moreover, the literature primarily uses life satisfaction as a measure of happiness (Welsch 2006; MacKerron and Mourato, 2009; Luechinger 2009, 2010; Menz and Welsch 2010; Menz 2011; Ferreira 2013; Ambrey 2014). Life satisfaction, an evaluative happiness measure, reflects one's overall assessment of life. Habituation to the environment may render reported life satisfaction a poor indicator of changes in welfare. In contrast, hedonic happiness refers to moment-to-moment experienced utility, which has a more direct link to immediate emotions and affection (Levinson 2012; Chen and Shi 2013; Deaton and Stone 2013). As noted in Zhang, Zhang and Chen (2015), the level of short-term air pollution is negatively associated with hedonic happiness, while it has little to do with life satisfaction.

Furthermore, most existing studies focus only on a single air pollutant. In this

[2] The happiness approach is not without its own weaknesses. For example, it treats stated well-being as a proxy for utility and makes interpersonal comparisons among respondents. Moreover, this approach only applies to public goods, such as air pollution, which vary across individuals in any given location and time. See an excellent discussion about advantages and disadvantages of these approaches by Levinson (2012).

study, we simultaneously estimate the willingness to pay for several major air pollutants, including but not limited to particulate matter with a diameter smaller than 2.5 micrometers (PM2.5). Because nationwide PM2.5 monitoring data was not released in China until 2014, our study is among the first to assess the monetary value of reducing PM2.5 in China. Previous studies have shown that finer particulate matter, such as PM2.5, tends to be more detrimental to health than larger particulates, such as those with a diameter smaller than 10 micrometers (PM10). 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). Exposure to PM2.5 may affect human capital formation in the long run (Lavy et al. 2014b).

Air pollution is generally worse in developing countries than developed countries (Chen et al. 2013; Greenstone and Hanna 2014; Tanaka 2015). For example, almost half of the Chinese population is exposed to PM2.5 at a level beyond the highest hazard threshold in the United States. Recently, the choking smog has galvanized public opinion in China, calling for more stringent environment regulations (*The Economist* 2015). Given that air pollution is ubiquitous in developing countries, the study on China may shed some light for other developing countries as well.

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 location of each interview. The well-matched air quality measure precisely captures environmental amenities that interviewees were exposed to. Because day-to-day fluctuations of air quality in a given location have little to do with the characteristics of individual respondents, air pollution exposures are literally random to survey subjects. This is a key assumption used in our empirical identification strategy.

We find that the concentration of particulate matter is negatively associated with people's hedonic happiness. People on average are willing to pay ¥539 ($88, or 3.8% of annual household per capita income) for a 1 μg/m^3 reduction in PM2.5 per year per person.[3] In other words, a one SD decline in PM2.5 raises an average person's happiness by an amount worth ¥49 ($8) per day. Our estimates are robust and consistent with comparable studies and may provide the first estimate for PM2.5 in China.

The rest of the paper 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

For happiness measures, we rely on the China Family Panel Studies (CFPS), a nationally representative survey of Chinese communities, families, and individuals. The CFPS is funded by Peking University and carried out by the Institute of Social Science Survey of Peking University. Respondents in the third wave of the CFPS survey conducted in year 2014 were asked to report the extent to which they felt it was difficult to be cheered up in the past month, ranging from 0 (*almost every day*) to 4 (*never*). The answer to this question forms the basis for the dependent variable. The higher the number, the happier the respondents were. In addition to happiness measures, the CFPS survey collects rich information at multiple levels, allowing us to control for a wide range of covariates. Moreover, the CFPS contains information about geographic locations and dates of interviews for all respondents, which enables us to precisely match individual happiness measures in the survey to local air quality data.

The air pollution measures come from the daily air quality report published by the Ministry of Environmental Protection of China (MEP). The report, which was not released until 2014, covers 947 monitoring stations including longitude and altitude information for each station. Six pollutants, including PM2.5, PM10, carbon monoxide (CO), nitrogen dioxide (NO_2), daily maximum ozone (O_3) and sulfur dioxide (SO_2), are used in our analysis. Figure A1 and Figure A2 indicate that PM2.5

[3] ¥539 corresponds to $87.74 using the average 2014 exchange rate 1 USD = 6.1434 CNY.

is highly concentrated and is a dominant source 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 consecutive daily records of rich weather conditions from 402 monitoring stations in China, such as temperature, precipitation, wind speed, and an indicator for bad weather.[4] Sunshine duration data 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 survey data 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.[5] The binary indicator for bad weather and the sunshine duration are obtained from the nearest monitoring station.

The 2014 wave of CFPS has 31,665 observations, of which 22,896 could be matched to air quality and weather data within 100 kilometers.[6] Due to some missing values for hedonic happiness and household demographics, the final dataset for analyses includes 21,589 observations.

3. Empirical Strategy

[4] Bad weather includes fog, rain/drizzle, snow/ice pellets, hail, thunder, and tornadoes/funnel clouds.
[5] See Ziebarth et al. (2014) for an example of this interpolation approach. 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.
[6] Counties unmatched to any air quality or weather monitoring station within 100 kilometers are dropped. The matching rate 72.3% (=22,896/31,665) is within a reasonable range. For example, a highly comparable study, Levinson (2012), was able to retain 52.3% of the observations when matching the U.S. General Social Survey with PM10 readings from the EPA's Air Quality System.

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 self-reported hedonic happiness of respondent i in county j at date t. The key variable P_{jt} is the air pollution in county j at date t. $\ln Y_{ijt}$ is the log form of household per capita income. We control for a set of demographic correlates of happiness X_{ijt}, including age and its squared term, gender, marital status, years of education, unemployment status, party membership, and health status (Oswald 1997; Knight, Song, and Gunatilaka 2009; Easterlin et al. 2012). We also control for a vector of rich weather conditions W_{jt}, involving sunshine duration, mean temperature and its squared term, total precipitation, mean wind speed, and a dummy for bad weather on the day of interview, to mitigate the concern that they are correlated with both hedonic happiness 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 1 describes key variables and their summary statistics.

[Insert Table 1]

By totally differentiating equation (1) and holding hedonic happiness constant (i.e., setting $dH = 0$), we calculate the average marginal rate of substitution between air pollution and household per capita income, $\partial Y / \partial P |_{dH=0} = -Y \hat{\alpha} / \hat{\beta}$, to assess a money metric value of air quality. This value is also known as “willingness to pay” (WTP), which represents the amount of annual income that people, on average, are willing to pay for a one-unit improvement in daily air pollution.

Figure A3 shows the distribution of interview dates for the CFPS 2014 national sample, which spans from July to December. Most surveys were conducted in July and August, as these two months largely overlapped with summer breaks during which many college students were hired as numerators for the CFPS. Our identification relies on variations in exposures to air pollution across similar respondents living in the same county in the same year. Since surveys lasted more than four months in most counties, there is substantial within-county variation of air quality in the survey period.

4. Results

4.1. Baseline Results

Table 2 reports the baseline estimates for various measures of air quality. Column (1) begins with PM2.5. Hedonic happiness decreases with PM2.5 on the day of interview and increases with annual household per capita income. A 1 μg/m^3 increase in PM2.5 leads to a decline in happiness by 0.565‰. A 1% increase in household per capita income raises happiness by 0.15‰. As reported in the last row of Table 2, according to a back-of-the-envelope calculation, 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. By plugging in -0.565‰ for $\hat{\alpha}$, 0.15‰ for $\hat{\beta}$, 14,313.90 for the mean household per capita income (in Chinese *yuan*), WTP corresponds to $\partial Y / \partial P$ =¥539, which indicates that a 1 μg/m^3 decline in PM2.5 raises an average person's happiness by an amount worth ¥539 ($87.74) per year per person, or ¥1.48 per day per person. To put this into context, note that the standard deviation (hereafter SD) of PM2.5 is 33.258 μg/m^3. The WTP amounts to ¥49 (=33.258×¥1.48) for a one SD decline in PM2.5 per day. In other words, people are on average willing to pay ¥49 ($7.98) per day for a one SD improvement in air quality.

[Insert Table 2]

Column (2) identifies the impact of particulate matter with a diameter between 2.5 and 10 micrometers (PM2.5-10). Unlike the coefficient for PM2.5, the coefficient for PM2.5-10 is insignificant and the calculated WTP is quite small. The different estimates between PM2.5 and PM2.5-10 suggest that people are much more willing to pay for a reduction in finer particulates (PM2.5) compared to coarse particulates (PM2.5-10). Considering that the WTP literature in China has largely focused on coarse particulates, this finding highlights the importance of giving special attention to finer particulates.

Column (3) estimates the WTP for a 1 μg/m^3 reduction in PM10.[7] Calculations based on the point estimate suggest a WTP of ¥334 (or 2.3% of annual income) for a 1 μg/m^3 reduction in PM10 per year. Similarly, Chen and Shi (2013) find that Chinese residents are willing to pay ¥355 (or 2.8% of annual income) for a 1 μg/m^3 reduction in PM10 per year. Levinson (2012) finds a WTP of $891 (or 2.1% of annual income) for U.S. residents.[8] Although people in the U.S. on average seem to be willing to pay a much higher amount in absolute terms, Chinese residents are more willing to pay a larger share of their income for air pollution mitigation than their U.S. counterparts.

Column (4) presents results for CO. The coefficient on CO is statistically insignificant. The corresponding WTP is only ¥5 for a one SD reduction per day, much less than the WTP for reduction in PM2.5. The difference may stem from the fact that CO is odorless, colorless and therefore less noticeable. Besides, CO only becomes a dominant source of air pollution for two percent of days throughout the year (Figure A2).

Similarly, the coefficient on NO_2 presented in Column (5) is statistically insignificant and the estimated WTP is ¥10 for a one SD reduction per day. According to the National Ambient Air Quality Standards (NAAQS) established by the United States Environmental Protection Agency (EPA), the primary and secondary standard for NO_2 is 53 ppb (100 μg/m^3).[9] In our sample, the mean and SD are both below this safety level, and thus NO_2 is not considered a major pollutant in China.

Column (6) estimates WTP for ozone. Though the coefficient on ozone is still statistically insignificant, the magnitude of WTP amounts to ¥42 for a one SD reduction per day. Ozone is a dominant source of air pollution for more than 10 percent of days each year (Figure A2), but in general the concentration level only causes discomfort among vulnerable populations, such as those with lung diseases.[10]

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[7] Mathematically, the WTP for PM10 should be a weighted average of WTPs for PM2.5 and PM2.5-10, where the weight depends on the PM composition in the air.

[8] $891 corresponds to ¥5,474.

[9] The Clean Air Act identifies two types of national ambient air quality standards. Primary standards provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.

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

The last column reports results for SO_2. Several papers examine the effects of annual average SO_2 on life satisfaction. For example, the average marginal WTP estimated in Luechinger (2010) is $312 (1.1% of annual income) for a 1 μg/m^3 reduction in SO_2 per year.[11] In our case, the coefficient on SO_2 is statistically insignificant and the corresponding estimated WTP is ¥664 (4.6% of annual income) for a 1 μg/m^3 reduction in pollution per year.

4.2. Robustness Checks

In this section, we perform a set of regressions to check the robustness of our main results. We focus on PM2.5 because it is associated with more detrimental effects on health and greater public awareness. Table 3 presents alternative specifications. Column (1) replicates the baseline results in Column (1) of Table 2 for ease of 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 amplifies, yielding higher WTP for PM2.5 reduction.

[Insert Table 3]

Daily PM2.5 on the date of interview may reflect longer-term pollution in a location. To mitigate this concern, column (3) adds average local PM2.5 over the month when the survey was conducted to control for the cumulative effects of air pollution. The coefficient for monthly PM2.5 level is negative and insignificant, while daily PM2.5 remains significant and is of similar size. The estimate of WTP for a one SD reduction in PM2.5 per day slightly declines from ¥49 to ¥48.

Column (4) estimates equation (1) using an ordered probit model. The coefficient on PM2.5 remains negative and significant. The calculated WTP for a one SD change in PM2.5 per day is slightly higher at ¥58.[12] Column (5) uses the log form of PM2.5 instead of the linear form of PM2.5 in the specification. Again, there is no substantial

[11] $312 is approximately ¥1,917.

[12] In the ordered probit model, the WTP is solved from the average marginal rate of substitution between pollution and income, keeping the latent variable constant.

change in the measured WTP.[13] Overall, our baseline results are robust to several specifications.

Another potential estimation issue is that the concentrations of various pollutants are often highly correlated and not distinguishable to survey subjects.[14] Therefore, estimated monetary values for a certain pollutant may inherently embody payment to other pollutants. To address this concern, we run the baseline result for PM2.5 by including daily measures of PM2.5-10, CO, NO_2, ozone and SO_2, respectively, as control variables. Table 4 reports the results. As shown in the table, the coefficients on PM2.5 and income remain essentially the same, while the additional pollutant is statistically insignificant, consistent with our baseline results in Table 2. Based on the coefficients for PM2.5 and income in the table, WTPs for a one SD change in PM2.5 per day remain within a reasonable range between ¥43 and ¥56.

[Insert Table 4]

In summary, the robustness tests in Table 3 and Table 4 provide us with a narrow range of WTPs between ¥43 and ¥61 associated with a one SD reduction in PM2.5 per day.

4.3. Heterogeneous Effects

This section examines the heterogeneous effect of air pollution on happiness and gauges WTPs across subgroups of population. First, responses to air quality may vary by education level. For example, lower education may restrict an individual's ability to acquire and digest information about air quality (Levinson 2012; Greenstone and Hanna 2014; Li, Folmer and Xue 2014). As revealed in Panel A of Table 5, more educated people are indeed willing to pay more for PM2.5 mitigation than less educated people.

[Insert Table 5]

Second, one's attitude toward pollution may also determine his/her reactions to air quality. CFPS 2014 includes a host of questions designed to assess peoples'

[13] In this case, the WTP is equal to $\partial Y/\partial P\big|_{dH=0} = -Y\hat{\alpha}/P\hat{\beta}$.

[14] Table A1 presents the correlations between the pollutants.

attitudes toward major social issues in China, including environmental quality.[15] Panel B divides the sample up by attitudes toward pollution. As shown in the panel, people who are critical about environmental issues are willing to pay more money for reducing PM2.5.

Further, we examine the differential impact on outdoor and indoor workers. While those working outdoors are exposed to more ambient air pollution, recent studies show that finer particulates can penetrate into a building and lead to a decline in indoor workers' productivity (Chang et al. 2014; Li, Liu, and Salvo 2015). Panel C of Table 5 lists the estimates on outdoor and indoor workers separately. Perhaps because people who work indoors often earn much higher income than those who work outdoors, they are also willing to pay more for improved air quality. However, outdoor workers are willing to pay a slightly higher share of income.

Lastly, families with small children are expected to 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 in Panel D of Table 5, families with young children are indeed willing to pay more for reduction in air pollution in both absolute amounts and in proportion to their incomes.

5. Conclusion

Matching hedonic happiness in CFPS, a nationally representative survey, with daily air quality data according to the exact dates and places of the interviews, this paper uses a happiness approach to estimate the monetary value of air quality. We find that the concentration of particulate matter has a significant negative effect on hedonic happiness. On average, people are willing to pay ¥539 ($88, or 3.8% of annual household per capita income) for a 1 μg/m^3 reduction in PM2.5 per year per person. Our estimates are robust and consistent with comparable studies and may provide the

[15] The question for environmental issues is framed as "How severe do you think the environmental problem is in China?" The answer ranges from 0 (*not severe at all*) to 10 (*very severe*). To mitigate the concern that some respondents may overstate or understate their general attitudes toward social issues, we calculate a normalized attitude score toward pollution by dividing the pollution assessment score by the average ratings of all eight questions. We divide our sample into two groups by the median of the normalized score.

first estimate for PM2.5 in China.

The population-weighted annual mean concentration of PM2.5 over 2014 in China is 68 μg/m^3, much larger than the primary and secondary standards in the NAAQS published by the EPA.[16] By reducing the annual mean PM2.5 to levels below the secondary standard, an average person's happiness will increase by an amount equal to ¥28,567 (US$4,651) per year, which is as high as 61.3 percent of GDP per capita in 2014.

Our results have important policy implications. China's 13th Five-Year Plan (2016-2020) strives for major progress in reducing air pollution. Specifically, the plan states that air quality of cities at and above the prefectural level must be good or excellent for 80 percent of days each year.[17] The optimal environmental regulations depend on the tradeoffs between their benefits and costs. Our valuations of air quality provide useful information on the benefits of tightening environment regulations.

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[16] The annual mean PM2.5 data at the city level are obtained from the "China Environmental Statistical Yearbook 2015", and the population data come from "China City Statistical Yearbook 2015". The primary and secondary standards of annual mean PM2.5 are 12 μg/m^3 and 15μg/m^3, respectively.

[17] Source: http://language.chinadaily.com.cn/2016-03/18/content_23944369_2.htm.

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Table 1: Summary statistics of key variables

Variable	Definition	Mean	Std. Dev.
Hedonic happiness	ranging from 0 to 4, higher numbers represent greater happiness	3.233	0.938
PM2.5	particulate matter with a diameter smaller than 2.5 micrometers ($\mu g/m^3$)	47.860	33.258
PM2.5-10	particulate matter with a diameter between 2.5 and 10 micrometers ($\mu g/m^3$)	34.111	21.163
PM10	particulate matter with a diameter smaller than 10 micrometers ($\mu g/m^3$)	81.056	46.709
CO	carbon monoxide ($\mu g/m^3$)	1.004×10^3	0.615×10^3
NO_2	nitrogen dioxide ($\mu g/m^3$)	28.938	14.878
O_3	ozone ($\mu g/m^3$)	119.921	59.105
SO_2	sulfur dioxide ($\mu g/m^3$)	22.065	20.621
Household per capita income	household per capita income (Chinese *yuan*)	14313.90	20583.91
Male	indicator for being male	0.486	0.500
Age (÷10)	age (÷10)	4.656	1.676
Married	indicator for being married	0.797	0.402
Education years	education years	7.489	4.980
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 2: Baseline results

Dependent variable	Pollutant						
Hedonic happiness	PM2.5 (μg/m^3)	PM2.5-10 (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)	(7)
Pollutant (÷1000)	-0.565**	-0.141	-0.350*	-2.836×10^{-3}	-0.256	-0.252	-0.696
	(0.242)	(0.631)	(0.211)	(0.014)	(0.991)	(0.155)	(0.617)
Household per capita income (log)	0.015**	0.014**	0.015**	0.015**	0.015**	0.014**	0.015**
	(0.006)	(0.007)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Male	0.097***	0.100***	0.097***	0.097***	0.097***	0.097***	0.097***
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Age (÷10)	-0.011	-0.008	-0.011	-0.011	-0.011	-0.012	-0.011
	(0.023)	(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**	0.005**
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Married	0.059***	0.056***	0.059***	0.059***	0.059***	0.059***	0.059***
	(0.019)	(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***	0.006***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Unemployed	-0.187***	-0.188***	-0.186***	-0.186***	-0.186***	-0.185***	-0.186***
	(0.062)	(0.064)	(0.062)	(0.063)	(0.063)	(0.063)	(0.062)
Party	0.033	0.035	0.033	0.033	0.033	0.033	0.033
	(0.024)	(0.025)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Chronic disease	-0.371***	-0.368***	-0.371***	-0.371***	-0.371***	-0.371***	-0.371***
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
County fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month, day-of-week fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	21,589	21,235	21,589	21,589	21,589	21,589	21,589
Adjusted R-squared	0.076	0.077	0.076	0.076	0.076	0.076	0.076
Mean household per capita income (Chinese *yuan*)	*14,313.90*	*14,313.90*	*14,313.90*	*14,313.90*	*14,313.90*	*14,313.90*	*14,313.90*
Std. Dev. of pollutant (μg/m^3)	*33.258*	*21.163*	*46.709*	*0.615×10^3*	*14.878*	*59.105*	*20.621*
% income to pay for a 1 μg/m^3 reduction per year	3.8%	1.0%	2.3%	18.9×10^{-3}%	1.7%	1.8%	4.6%
WTP for a 1 μg/m^3 reduction per year	¥539	¥144	¥334	¥3	¥244	¥258	¥664
WTP for a one std. dev. reduction per day	¥49	¥8	¥43	¥5	¥10	¥42	¥38

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 3: Robustness checks - alternative specifications

Dependent variable	Baseline	Add lagged PM2.5	Add average PM2.5	Ordered probit	PM2.5 in log form
Hedonic happiness	(1)	(2)	(3)	(4)	(5)
PM2.5 (÷1000)	-0.565**	-0.695***	-0.550**	-0.887***	-33.652**
	(0.242)	(0.251)	(0.230)	(0.317)	(13.904)
lagged PM2.5 (÷1000)		0.254			
		(0.313)			
Average PM2.5 by county and month (÷1000)			-0.182		
			(1.084)		
Household per capita income (log)	0.015**	0.015**	0.015**	0.020**	0.015**
	(0.006)	(0.006)	(0.006)	(0.008)	(0.006)
Observations	21,589	21,589	21,589	21,589	21,588
Adjusted R-squared	0.076	0.076	0.076	0.044	0.076
Mean household per capita income (Chinese *yuan*)	*14,313.90*	*14,313.90*	*14,313.90*	*14,313.90*	*14,313.90*
Std. Dev. of PM2.5 (μg/m^3)	*33.258*	*33.258*	*33.258*	*33.258*	*33.258*
% income to pay for a 1 μg/m^3 reduction per year	3.8%	4.6%	3.7%	4.4%	4.7%
WTP for a 1 μg/m^3 reduction per year	¥539	¥663	¥525	¥635	¥671
WTP for a one std. dev. reduction per day	¥49	¥60	¥48	¥58	¥61

Source: China Family Panel Studies 2014.

Note: Other covariates and fixed effects are the same as those in Column (1) of Table 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 4: Robustness checks – addressing correlations between PM2.5 and other pollutants

Dependent variable	Pollutant					
Hedonic happiness	PM2.5	PM2.5 and PM2.5-10	PM2.5 and CO	PM2.5 and NO_2	PM2.5 and O_3	PM2.5 and SO_2
	(1)	(2)	(3)	(4)	(5)	(6)
PM2.5 (÷1000)	-0.565**	-0.601**	-0.644***	-0.618**	-0.496*	-0.512**
	(0.242)	(0.282)	(0.244)	(0.239)	(0.254)	(0.252)
Second pollutant (÷1000)		0.245	0.012	0.401	-0.176	-0.411
		(0.680)	(0.015)	(1.031)	(0.163)	(0.644)
Household per capita income (log)	0.015**	0.014**	0.015**	0.015**	0.015**	0.015**
	(0.006)	(0.007)	(0.006)	(0.006)	(0.006)	(0.006)
Observations	21,589	21,235	21,589	21,589	21,589	21,589
Adjusted R-squared	0.076	0.077	0.076	0.076	0.076	0.076
Mean household per capita income (Chinese *yuan*)	*14,313.90*	*14,313.90*	*14,313.90*	*14,313.90*	*14,313.90*	*14,313.90*
Std. Dev. of pollutant ($\mu g/m^3$)	*33.258*	*33.258*	*33.258*	*33.258*	*33.258*	*33.258*
% income to pay for a 1 $\mu g/m^3$ reduction per year	3.8%	4.3%	4.3%	4.1%	3.3%	3.4%
WTP for a 1 $\mu g/m^3$ reduction per year	¥539	¥614	¥615	¥590	¥473	¥489
WTP for a one std. dev. reduction per day	¥49	¥56	¥56	¥54	¥43	¥45

Source: China Family Panel Studies 2014.

Note: Other covariates and fixed effects are the same as those in Column (1) of Table 2. Robust standard errors, clustered at the county level, are presented in parentheses. *10% significance level. **5% significance level. ***1% significance level. The WTP calculations in columns (2) through (6) are based on the coefficients on PM2.5 and household per capita income.

Table 5: Heterogeneous effects of PM2.5 and their corresponding WTPs

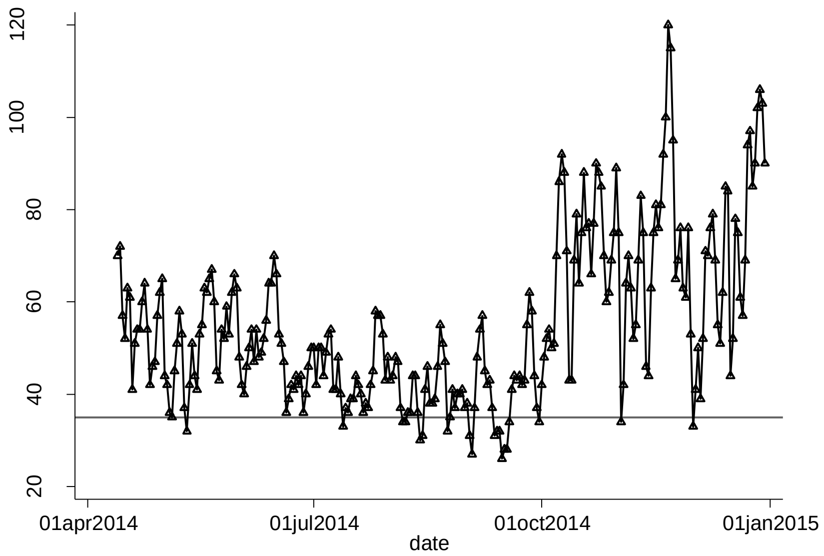
Dependent variable	A. Education		B. Pollution attitude	
Hedonic happiness	educated	less educated	critical	careless
	(1)	(2)	(3)	(4)
PM2.5 (÷1000)	-0.712**	-0.293	-0.705**	-0.432
	(0.301)	(0.366)	(0.317)	(0.337)
Household per capita income (log)	0.017**	0.008	0.016*	0.013
	(0.007)	(0.009)	(0.008)	(0.010)
Observations	12,012	9,577	10,808	10,545
Adjusted R-squared	0.068	0.091	0.070	0.083
Mean household per capita income (Chinese *yuan*)	*17,315.73*	*10,548.83*	*15,495.80*	*13,209.61*
Std. Dev. of PM2.5 (μg/m^3)	*33.531*	*32.856*	*32.910*	*33.641*
% income to pay for a 1 μg/m^3 reduction per year	4.2%	3.7%	4.4%	3.3%
WTP for a 1 μg/m^3 reduction per year	¥725	¥386	¥683	¥439
WTP for a one std. dev. reduction per day	¥67	¥35	¥62	¥40
Dependent variable	C. Workplace		D. Children younger than six	
Hedonic happiness	indoors	outdoors	yes	no
	(5)	(6)	(7)	(8)
PM2.5 (÷1000)	-0.724**	-0.530*	-1.182*	-0.553**
	(0.331)	(0.296)	(0.674)	(0.244)
Household per capita income (log)	0.020**	0.014*	0.020	0.017**
	(0.010)	(0.008)	(0.017)	(0.007)
Observations	10,009	12,087	2,548	18,519
Adjusted R-squared	0.071	0.082	0.069	0.080
Mean household per capita income (Chinese *yuan*)	*19,297.85*	*10,595.18*	*13,285.85*	*14,617.96*
Std. Dev. of PM2.5 (μg/m^3)	*33.300*	*33.861*	*34.507*	*32.957*
% income to pay for a 1 μg/m^3 reduction per year	3.6%	3.8%	5.9%	3.3%
WTP for a 1 μg/m^3 reduction per year	¥699	¥401	¥785	¥476
WTP for a one std. dev. reduction per day	¥64	¥37	¥74	¥43

Source: China Family Panel Studies 2014.

Note: Other covariates and fixed effects are the same as those in Column (1) of Table 2. Robust standard errors, clustered at the county level, are presented in parentheses. *10% significance level. **5% significance level. ***1% significance level.

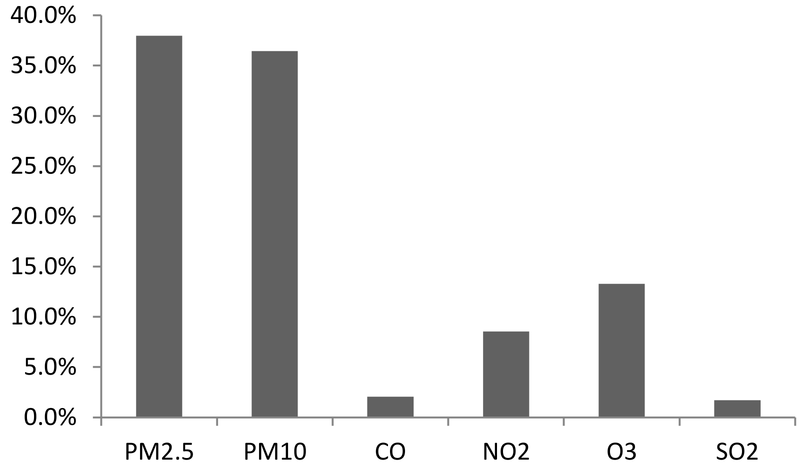
Online Appendix A: Supplementary Figures and Tables

Figure A1: Daily mean PM2.5 (μg/m³) in China



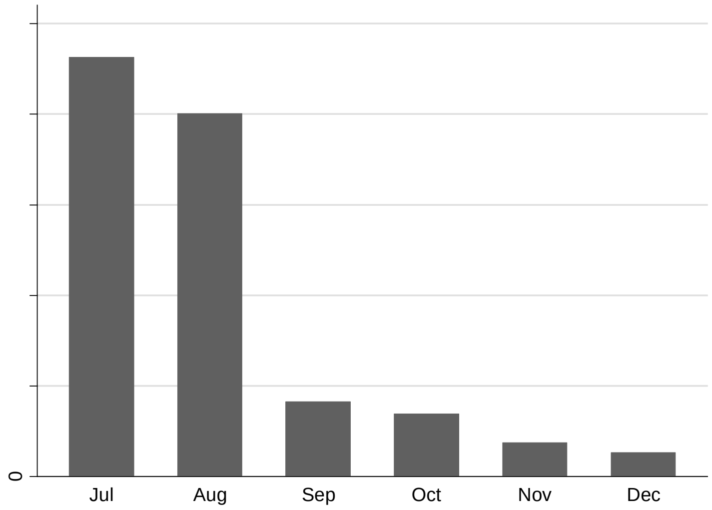
Source: The Ministry of Environmental Protection of the People's Republic of China.
Note: PM2.5 = particulate matter with a diameter smaller than 2.5 micrometers. The primary and secondary standards of daily mean PM2.5 in NAAQS published by EPA is 35 μg/m³.

Figure A2: Distribution of dominant pollutants in air



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 A3: 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.

Table A1: Correlations between pollutants

	PM2.5 (μg/m^3)	PM2.5-10 (μg/m^3)	CO (μg/m^3)	NO_2 (μg/m^3)	O_3 (μg/m^3)	SO_2 (μg/m^3)
PM2.5 (μg/m^3)	1.000					
PM2.5-10 (μg/m^3)	0.463	1.000				
CO (μg/m^3)	0.402	0.282	1.000			
NO_2 (μg/m^3)	0.467	0.475	0.354	1.000		
O_3 (μg/m^3)	0.187	0.192	0.042	0.129	1.000	
SO_2 (μg/m^3)	0.395	0.366	0.333	0.467	0.067	1.000

Note: CO = carbon monoxide. NO_2 = nitrogen dioxide. O_3 = ozone. PM2.5 = particulate matter with a diameter smaller than 2.5 micrometers. PM2.5-10 = particulate matter with a diameter larger than 2.5 micrometers and smaller than 10 micrometers. SO_2 = sulfur dioxide.