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Happiness in the Air: How Does a Dirty Sky Affect Subjective Well-being?

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August 2015

Forschungsinstitut
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ABSTRACT

Happiness in the Air: How Does a Dirty Sky Affect Subjective Well-being?*

Existing studies that evaluate the impact of pollution on human beings understate its negative effect on cognition, mental health, and happiness. This paper attempts to fill in the gap via investigating the impact of air quality on subjective well-being using China as an example. By matching a unique longitudinal dataset at the individual level, which includes self-reported happiness and mental well-being measures, with contemporaneous local air quality and weather information according to the exact date of interview, we show that worse air quality reduces shorter-term hedonic happiness and increases the rate of depressive symptoms. However, life satisfaction, an evaluative measure of happiness, is largely immune from immediate bad air quality.

JEL Classification: I31, Q51, Q53

Keywords: hedonic happiness, life satisfaction, mental well-being, air quality, China

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1. Introduction

It has been well documented that exposure to air pollution increases health risks, such as cardiovascular diseases (Gallagher et al. 2010), respiratory diseases (Beatty and Shimshack 2014), and even mortality (Chen et al. 2013). However, less is known about how air pollution affects the subjective dimension of well-being. Studies on the latter aspect have the potential to improve happiness, arguably the ultimate goal of human beings.

Among the few existing studies on this linkage between air pollution and happiness, most rely on either aggregate air pollution and happiness data (Menz 2011) or cross-sectional individual-level data (Levinson 2012). Studies based on aggregated data, however, are subject to the *ecological fallacy*. That is, the findings may differ or even contradict each other depending on the levels of aggregation. Studies at the individual level on the basis of cross-sectional data, on the other hand, are prone to estimation biases because not all the individual-specific factors can be taken into account.

Moreover, almost all the studies use air quality data averaged over a rather long period, such as one year (Ferreira et al. 2013). The average air quality data from a long span may differ from the actual data on the day of the interview, which should more directly affect interviewees' responses to subjective well-being (SWB) questions. The associated measurement errors of air quality also could result in biased estimates.

Finally, the literature primarily uses life satisfaction, an evaluative measure of SWB, or makes no explicit distinction between hedonic and evaluative measures (Levinson 2012). Hedonic happiness refers to moment-to-moment experienced utility and directly links to immediate emotions and affection, while evaluative happiness reflects an overall assessment of life. As noted in Kahneman and Deaton (2010) and Deaton and Stone (2013), the two measures could yield drastically different results because they are often influenced by different factors.

To overcome these problems, we employ a novel national longitudinal survey of individuals, with rich measures of both hedonic and evaluative happiness, in

combination with contemporaneous local air quality and weather information at the time and location of the interview. The matched longitudinal data enable us to remove individual unobserved factors, thus largely alleviating omitted variable biases. The local air quality on the day of the interview can more precisely reflect environmental amenities facing interviewees than the heretofore more often used measure of average air quality during a long span.

Based on the matched longitudinal dataset of SWB and daily air quality, we find that lower air visibility significantly reduces shorter-term hedonic happiness and raises the rate of depressive symptoms. The impact on life satisfaction, however, is largely muted, possibly due to hedonic adaptation over time. An increase of 1 standard deviation (*SD*) in air visibility boosts hedonic happiness (scaled from 1 to 4) by 0.043, slightly less than the impact of relative income status (0.064), which is one of the most important determinants of happiness in the literature. A back-of-the-envelope analysis indicates that the decline in visibility accounts for 6.6 percent of the actual decline in happiness during the period from 1997 through 2012. Putting this into monetary terms, people on average are willing to pay CNY 2.9 per day per person (more than US$170 per year per person) for a 0.1 *SD* improvement in air quality.[1]

To the best of our knowledge, this is the first study examining the impact of air quality on SWB in a developing country. Compared to air pollution in developed countries, air pollution is generally more serious, sometimes even life threatening, in developing countries (Tanaka 2012; Chen et al. 2013; Greenstone and Hanna 2014). There is thus a need for more empirical evidence on the impact of air quality on human welfare.

Our study also is related to a few strands of literature. It contributes to the debate about the Easterlin paradox, that is, the observation that over time happiness does not go up despite income growth. Few studies have explained the puzzle from the viewpoint of air quality, which is the focus of our paper. Worsening air quality accompanying economic growth in less-developed countries might reduce people's happiness. It also

[1] All dollars are US dollars.

adds to the burgeoning body of literature on the impact of air pollution on various outcomes, such as standardized test scores, human capital formation, later labor market outcomes (Lavy, Ebenstein, and Roth 2014a, 2014b), and the productivity of indoor workers (Chang et al. 2014; Li, Liu, and Salvo 2015). Long-term exposure to air pollution may even change the structure and function of brains (Weir 2012). The associated long-term economic consequences identified in the literature and the sizable willingness-to-pay (WTP) to improve air quality from our back-of-the-envelope calculation warn us that careful evaluations of the impact of air pollution on SWB are necessary.

The reminder 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 heterogeneity tests. Section 5 discusses implications for the Easterlin paradox. Finally, section 6 concludes.

2. Data

2.1. SWB

For happiness measures, we rely on the China Family Panel Studies (CFPS), a nationally representative survey of Chinese communities, families, and individuals conducted in 2010 and 2012. The CFPS is funded by Peking University and carried out by the Institute of Social Science Survey of Peking University. The CFPS covers a wide range of domains for families and individuals from 162 counties in 25 provinces of China, including their economic activities, education outcomes, family dynamics and relationships, health, and SWB.

There are four advantages of the CFPS for our purposes. First, information about geographic locations and dates of interviews for all respondents enables us to precisely match individual happiness measures in the survey with external air quality data. Second, rich measures of happiness ranging from moment-to-moment happiness to mental well-being and life satisfaction allow us to compare the effects of air pollution in various time frames. Third, the longitudinal data allow us to remove unobserved

individual factors that may bias the results. Fourth, 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. The first is life satisfaction (Welsch 2006, 2007; Rehdanz and Maddison 2008; MacKerron and Mourato 2009; Luechinger 2009, 2010; Menz 2011; Ferreira et al. 2013). Both the CFPS 2010 and the CFPS 2012 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*). Panels are constructed to implement individual fixed effect estimations. 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 is the Center for Epidemiologic Studies Depression scale (CES-D), a self-reported scale designed to measure the current level of depressive symptomatology in the general population. Compared to life satisfaction, the CES-D highlights emotional experiences that affect people during a shorter period.

The CFPS 2012 uses a standard 20-item scale developed by Radloff (1977) (Appendix B). There are four options for each item, scaled from 0 (*rarely or none of the time*) to 3 (*most or all of the time*). Four items (4th, 8th, 12th, and 16th) worded in inverse order in the CES-D are transformed back to be consistent with other items. The total CES-D score is valued between 0 and 60, with higher scores indicating more negative symptoms during the past week. Along with the continuous CES-D score, two cut-off scores indicate depression, namely, depressive symptoms (for example, 16 or greater) and severe depressive symptoms (for example, 21 or greater) (Radloff 1977; Bailly, Beuscart, and Collinet 1992).

However, the CFPS 2010 implements only a short form six-item CES-D test (Appendix B). We therefore construct a balanced panel and generate the percentile of the total CES-D score, respectively, for CFPS 2010 and CFPS 2012 for each respondent, which helps link the two waves of survey data in the longitudinal analysis.

The third SWB measure gauges short-term hedonic happiness. The CFPS 2012

asked respondents to answer the question, "I was happy" with a number between 1 and 4. The higher the number, the happier the respondent was during the past week. Compared to life satisfaction, CES-D score and hedonic happiness are more directly related to the environment and people's affective state in day-to-day and moment-to-moment life (Stone and Mackie 2014).[2]

2.2. Air Quality

We use two measures of air quality, the air pollution index (API) and air visibility. The first measure, API, ranges from 0 to 500, and a larger value indicates worse air quality. API is generated by a piecewise linear transformation from the concentrations of three air pollutants, including sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and fine particulate matter smaller than 10 micrometers (PM10). Evidence suggests that fine particulate matter is detrimental to health and human capital (Cohen et al. 2005; Lavy, Ebenstein, and Roth 2014a, 2014b) and is of high concentration in China (Li, Liu, and Salvo 2015).

Daily observations of API are obtained from the air quality report published by the Ministry of Environmental Protection of China. The report, which started in June 2000 and covered 120 major cities in 2012, involves all the provincial municipalities and provincial capitals across all regions in China (Figure A1). However, our knowledge of API and composition of air pollution relies mainly on daily reports, which were not on the radar of public media during the CFPS survey period (2010–2012). For example, keyword searches of "wumai (haze)" and "kouzhao (mask)" using China's major search engine, baidu.com, indicate that public awareness did not spike until a major crisis of thick haze covering much of eastern China in early 2013 (Figure A2). Moreover, it is concerning that API reports by the local government are less reliable than external sources, especially due to the possible manipulation of daily API to reach the standard of a "blue-sky day" (Chen et al. 2012; Ghanem and Zhang 2014).

The second measure, air visibility, is defined as the greatest distance at which an

[2] 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.

observer can just see a black object viewed against the horizon (Malm 1999). Atmospheric researchers confirm visibility is a good predictor of main air pollutant concentrations, such as fine particulate matter, SO_2, and NO_2 (Lee and Sequeira 2001; Qiu and Yang 2000; Cheung et al. 2005; Deng et al. 2008).[3]

Monitored by the National Climatic Data Center of the National Oceanic and Atmospheric Administration, air visibility complements API in measuring air quality. First, air visibility is much easier to perceive than the colorless components in the API, including SO_2 and NO_2. Second, this external source of air quality data is less likely to be manipulated and is therefore more reliable. Third, relative to API, visibility stations are more evenly distributed in China during a longer period, and therefore air visibility is more nationally representative and better matches the CFPS surveys (Figure 1). Daily air visibility records are from 400 monitor stations in China between 2009 and 2012, much larger than the number of monitor stations for API. Fourth, the longitudes and latitudes of visibility monitor stations facilitate us to more precisely measure distances away from monitors. Fifth, the air visibility data record rich weather conditions, such as temperature, precipitation, wind speed, and indicators for bad weather,[4] which isolates the impact of air quality from weather patterns and therefore mitigates potential estimation biases.

[Insert Figure 1]

To merge the CFPS survey with air visibility and weather data, we calculate a weighted average value of all the monitor stations within 60 kilometers of the centroid of each CFPS surveyed county, where the weights are equal to the inverse of the square root of the distance between the monitor stations and county centroids.[5,6] Meanwhile, we match each CFPS county to the nearest city with an API report.[7]

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[3] See Figure A3 for an example of Lanzhou, the capital city of Gansu province, from 2009 to 2012, where individual pollutant components are available. Visibility is observed to be highly negatively correlated with the three main pollutants, indicating air visibility is a good proxy for air quality.

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

[5] One exception is that the bad weather indicator is matched to the nearest monitor to each county.

[6] Our baseline results are robust to matching using narrower radiuses (for example, 50 kilometers) and alternative weights (for example, inverse of the distance or squared distance between the monitor stations and the county centroids).

[7] We do not calculate weighted air pollution index (API) for two reasons: one, API depends on the local

The CFPS surveyed a balanced panel of 22,429 individual respondents (or 44,858 observations) in 2010 and 2012, of which 29,830 observations could be matched to air visibility and weather data within 60 kilometers of the county centroids.[8] Among the 29,830 observations, API readings are missing for 3,065 observations when matched with the air quality report published by the Ministry of Environmental Protection of China in 2010, and self-rated relative income statuses are missing for 2,381 observations. The final dataset for analyses includes 27,433 observations and 24,753 observations after merging with the visibility data and the API data, respectively.[9] The differences in sample size among regressions are due to a small but different number of missing values for various SWB measures.

3. Empirical Strategy

Our baseline econometric specification is as follows:

$$\begin{aligned} H_{ijt} &= \alpha_1 \ln P_{jt} + \alpha_2 \ln sunshine_{jt} + \alpha_3 \ln P_{jt} \times \ln sunshine_{jt} \\ &\quad + \beta_1 \ln Y_{ijt} + \beta_2 R_{ijt} + X'_{ijt} r + W'_{jt} \phi + \lambda_i + \delta_j + \eta_t + \varepsilon_{ijt} \end{aligned} \tag{1}$$

The dependent variable H_{ijt} is the self-reported happiness of respondent i in county j at date t. $\ln P_{jt}$ is the log form of air quality measure in county j at date t. We add $\ln sunshine_{jt}$, the log form of sunshine duration (hours) in county j at date t, as a key explanatory variable. Studies show that sunshine affects individuals' moods, social behavior, and health. For example, sunshine can significantly increase people's willingness to help and generosity of tips (Cunningham 1979). People born in the winter suffer a higher risk of schizophrenia than those born in sunnier months (Wolfson 2013). Though there is no record of sunshine hours, we calculate approximate hours of sunshine in county j at date t according to the latitude of county j and the latitude of direct sunshine point at date t (Appendix C). $\ln P_{jt} \times \ln sunshine_{jt}$, an interaction term

dominant pollutant, and two, the officially released API data are from far fewer monitor stations than air visibility data.

[8] Counties unmatched to any visibility stations within 60 kilometers of their centroids are dropped. The matching rate 66.5% (=29830/44858) is higher than other studies. For example, one of the most comparable studies to us, Levinson (2012), was able to maintain 52.3% of the observations when matching the U.S. General Social Survey with PM10 readings from the EPA's Air Quality System.

[9] A balance test shows that there are no significant differences in observed characteristics between the matched and unmatched samples, mitigating the concern for selection bias in our matching process.

between $\ln P_{jt}$ and $\ln sunshine_{jt}$ captures the interactive effect between air quality and hours of sunshine.

We test whether air quality has a positive effect on SWB. However, it is likely that people may prefer a less clear sky on hot summer days with longer hours of sunshine. Because most of the CFPS interviews were conducted when college students were in summer vacation (Figure A4), it is necessary to test whether longer hours of sunshine weaken the positive effect of clear skies on SWB. Specifically, when P_{jt} represents air visibility and H_{ijt} denotes life satisfaction or hedonic happiness, we hypothesize that α_1 is significantly positive and α_3 is significantly negative.

We control for the log form of absolute household per capita income $\ln Y_{ijt}$; the self-rated relative income status R_{ijt} ranging from 1 (*lowest*) to 5 (*highest*); a set of demographic correlates of happiness X_{ijt}, including age and its square term; gender; marital status;[10] years of education; occupation; unemployment status; party membership; and health status (Oswald 1997; Knight, Song, and Gunatilaka 2009; Knight and Gunatilaka 2010, 2011; Easterlin et al. 2012) and a vector of weather conditions W_{jt}, involving mean temperature and its square term; daily maximum-minimum temperature gap; total precipitation; maximum sustained wind speed; and a dummy for bad weather on the day of observation. We control for rich weather conditions to rule out the possibility that they are correlated with both SWB and air quality and therefore bias our results. The daily maximum-minimum temperature gap serves as a proxy for cloud cover of the day since a smaller gap usually indicates a higher chance of cloudy weather (Mearns and Best 2013). Controlling for the temperature gap also may mitigate potential biases of theoretical sunshine hours and visibility due to cloud cover. λ_i denotes individual fixed effect; δ_j represents county fixed effect; η_t indicates month, year, and day-of-week fixed effects; and ε_{ijt} is the error term. Standard errors are clustered at the county level. Table 1 describes key

[10] Marital status includes those never married, married, and divorced. We set those never married as the reference group.

variables and their summary statistics.

[Insert Table 1]

Figure A4 shows the distribution of interview dates for the two waves of the CFPS national sample, which span all months and seasons and thus enable us to isolate the impact of air pollution from seasonality. Overall, a majority of surveys were conducted in summer or winter as those seasons largely overlap with the summer vacation and winter break of the college students who implemented the CFPS. Variations for identification in our individual fixed effect model (equation 1) come from differential exposure to air pollution for the same respondent across the two waves. The average absolute change in visibility for each individual across waves amounts to 2.83 miles. For outcome indicators available in only one of the two waves, such as hedonic happiness, our estimation strategy relies on differential exposure to air pollution for different respondents living in the same county in the same wave of the survey.

Before undertaking quantitative analyses, we plot the relationships between air visibility and main SWB measures (Figure 2). We first generate the visibility residuals by regressing visibility on county fixed effects, year and month fixed effects, and rich weather conditions. We plot the mean of visibility residuals within each level of life satisfaction, CES-D score, and hedonic happiness. As shown in Figure 2, life satisfaction and hedonic happiness demonstrate a positive relationship with air visibility, while CES-D score has a negative relationship, in accordance with our expectation. While these bivariate plots provide some suggestive evidence, we present a more rigorous analysis in the next section.

[Insert Figure 2]

4. Results

4.1. Baseline Results

We report baseline results on air quality and various SWB measures. To save space, our preferred specifications in columns (4) and (8) of Table 2 through Table 6 highlight our main interested variables. The corresponding full estimation results are presented

in Table A1 through Table A5, respectively.

Table 2 presents longitudinal evidence on life satisfaction. Columns (1) through (4) approximate air quality by air visibility. Column (1) identifies the effect of air quality while controlling for demographic characteristics and individual fixed effects. We do not find a significant relationship between daily air quality and life satisfaction. Relative income imposes a highly significant effect on life satisfaction, while there is no significant effect for absolute income. People who are in poor health or divorced tend to have lower life satisfaction. Column (2) further adds sunshine hours and its interaction with visibility. The coefficient of air visibility remains insignificant, as do the coefficients on sunshine hours and the interaction term. Moreover, our main results stay robust when rich weather conditions and year, month, and day-of-week fixed effects are further controlled for in columns (3) and (4).

Columns (5) through (8) repeat the exercises in columns (1) through (4), using API as a measure of air quality. The coefficients of API and its interaction with sunshine remain insignificant in all the specifications, suggesting that short-term air quality has little impact on long-term life evaluation.

[Insert Table 2]

Table 3 examines the effect of air quality on hedonic happiness. Since hedonic happiness was surveyed only in the CFPS 2012, we report cross-sectional evidence with county fixed effects in all specifications. Both higher air visibility and lower API significantly improve hedonic happiness. Consistent with the happiness literature, there is a U-shaped relationship between age and hedonic happiness, and the trough of hedonic happiness is around age 61. Married men who receive more education and are healthier tend to be happier. Party membership is associated with being happier, presumably because it symbolizes higher social status and social recognition.

Column (2) of Table 3 adds sunshine hours of the day and its interaction with air visibility. As expected, hedonic happiness increases with both visibility and hours of sunshine on the day of interview but decreases with the interaction between visibility and sunshine. Columns (3) and (4) further control for seasonality and weather-related effects by including rich weather conditions and month and day-of-week fixed effects.

Our main results remain robust to these additional controls. The insignificant sunshine effect in column (4) may be due to its colinearity with month fixed effects.

Columns (5) through (8) of Table 3 reestimate columns (1) through (4) after replacing air visibility with API and generate consistent results. Specifically, API has a significant and negative effect on hedonic happiness, and the effect is partially offset by long hours of sunshine. Therefore, evidence from both China-monitored API data and US-monitored air visibility data suggests a salient impact of air quality on hedonic happiness.

[Insert Table 3]

Though only a six-item CES-D was collected in the CFPS 2010, rendering it incompatible with the 20-item CES-D in the CFPS 2012, we restrict the analysis to the balanced panel and transform CES-D scores in each wave to their corresponding percentiles. The lower the percentile in the CES-D score distribution, the lower the chance of depression. Now we are able to implement all estimations in Table 4 with individual fixed effects as we did in Table 2. In column (1) of Table 4, the coefficient on visibility is negative but statistically insignificant, which becomes significant when hours of sunshine and the interaction term are included in columns (2) and (4). The effect of air visibility is robust to the inclusion of rich weather conditions and year, month, and day-of-week fixed effects. The results using API in columns (5) through (8) reveal the same pattern, further indicating that good air quality improves mental well-being.

[Insert Table 4]

Table 5 and Table 6 repeat the estimations with two binary measures of mental well-being, namely, depressive symptoms (with CES-D score greater than 15) and severe depressive symptoms (with CES-D score greater than 20). Since there are no depressive symptom cut-offs for the six-item CES-D, we have to rely on cross-sectional estimations. As shown in columns (2) through (4) of Table 5 and Table 6, after controlling for demographic characteristics of the respondents, low visibility on the day of interview is positively correlated with the chances of depressive symptoms and severe depression. In contrast, API does not seem to have any significant effect.

[Insert Table 5]

[Insert Table 6]

If contemporary exposure to air pollution is really the driving force of the observed decline in hedonic happiness and mental well-being, we should observe no such effect when the timing of air pollution and the date of interview are mismatched. Results from the placebo test that forwards air visibility by a week (Table A6) indeed suggest that no unobserved factors drive the observed pattern between air quality and SWB.

Life satisfaction is largely immune to short-term variations in air pollution (Table 2), so we further investigate to what extent they are susceptible to deviation of pollution from various time trends, such as a week, a month, a season, and a year. One would hypothesize that a greater deviation from these pollution trends may generate a larger impact on life satisfaction. Results in Table 7 (columns [1] through [4] for visibility and columns [5] through [8] for API), however, suggest that life satisfaction is not sensitive to deviations from these trends.

[Insert Table 7]

The muted impact on life satisfaction probably can be explained by *hedonic adaptation*, processes that attenuate the long-term emotional impact of unfavorable circumstances. Hedonic adaptation is often evolutionarily optimal in protecting people from adverse mental reactions, preventing the continued expenditure of energy on futile attempts to change the unchangeable and redirecting motivation to changes that can be made (Frederick and Loewenstein 1999). For example, the level of air pollution that was previously very hedonically negative may become hedonically neutral over time as people transition the neutral reference point from lower to higher levels of pollution.

4.2. Heterogeneity of the Effect

Our baseline results suggest that the main effect of air quality is on hedonic happiness and mental well-being. This section further investigates heterogeneous effects, which may help us understand the potential pathways by which air quality affects SWB.

Table 8 presents results of responses to air quality by gender and age, respectively.

Apparently females respond more strongly to air pollution than do males, while the elderly are more sensitive to air quality than are other age cohorts. This is probably because senior people spend more time outdoors and therefore care more about air quality. Table A7 further shows the impact on men and women by age. The impact is particularly strong for older women.

[Insert Table 8]

If air quality is a normal good, we would expect that sensitivity to air pollution would increase with income. To test this hypothesis, we divide the respondents into four groups by quintiles of household per capita income. Results in Table 9 confirm that the poor are less responsive to air quality than are the rich.

[Insert Table 9]

Attitude toward pollution may also affect reaction to air quality. CFPS 2012 includes a host of questions to elicit people's attitudes toward major social issues in China, such as inequality, environmental quality, social security, education, and corruption.[11] The first two columns of Table 10 divide the sample by attitude toward environmental quality, and results suggest that air quality imposes larger and more significantly positive effects on people who are more critical about environmental issues.

Workplace may play an important role in affecting people's response to air quality. An increase in particulate matter outdoors even leads to a significant reduction of indoor worker productivity (Chang et al. 2014; Li, Liu, and Salvo 2015). We test whether air quality imposes large impacts on the SWB of people working outdoors and indoors. Results presented in the last two columns of Table 10 show that bad air quality reduces hedonic happiness only among people who work outdoors, but it affects the mental well-being of all people no matter whether they work indoors or outdoors.

[Insert Table 10]

[11] The question about the environmental issue is framed as, "How severe do you think is the environmental problem in China?" The answer is rated by a number ranging 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.

Do people living in more polluted areas respond to air pollution differently from those in less polluted areas? On the one hand, both the dose-response relationship and increasing marginal disutility from air pollution may mean that heavier air pollution generates larger negative impacts on SWB. On the other hand, people in more polluted areas could be less sensitive to air pollution either because they are habituated to the poor air quality or because people who are less concerned about air pollution sort into more polluted areas ex ante. We divide the whole sample by the median level of yearly average visibility. Results in columns (1) through (2) of Table 11, similar to Levinson (2012), show significant effects of air pollution only in less polluted areas, indicating that habituation and potential self-selection may dominate the dose-response relationship between air pollution and SWB.

We expect people in poor health to be more emotionally vulnerable to air pollution. Columns (3) through (4) of Table 11 divide the sample by chronic disease status. Those who suffer from chronic diseases, such as asthma and heart attacks, demonstrate more salient negative impacts of air pollution.

[Insert Table 11]

Moreover, less educated people may be less concerned about air quality as low education may restrict their ability to acquire information about air quality through, for example, smart phones or the Internet (Levinson 2012; Greenstone and Hanna 2014). We test this hypothesis taking advantage of two sources of air pollution data. Air visibility is presumably easier to perceive than API as the latter requires additional information and certain knowledge. Dividing the whole sample by education, Table 12 indicates that those who receive more education react more to both visibility and API than do the less educated.

[Insert Table 12]

Finally, it is likely that households with children are more sensitive to air pollution. We separate the sample by whether a household has young children (that is, children younger than age 16) but find no distinguishable differences between the two.

5. Implications For the Easterlin Paradox

Following the seminal work of Easterlin (1974, 1995), there has been a growing literature explaining the happiness puzzle, also known as the Easterlin paradox, that income growth does not necessarily improve (hedonic) happiness.[12] Concern for relative income has been regarded as the most plausible explanation for the paradox (Luttmer 2005; Clark, Frijters, and Shields 2008; Chen 2015b). Other plausible driving forces include the framing of happiness questions (Graham, Chattopadhyay, and Picon 2010), income measurement errors (Graham, Chattopadhyay, and Picon 2010), and omitted factors (for example, social trust and freedom) (Helliwell 2012; Inglehart et al. 2008).

In this paper, we argue for the first time that air pollution is another plausible contributor to the paradox. We compute the economic significance of air pollution, relative income, and other correlates on the declining level of happiness and evaluate their importance in explaining the Easterlin paradox in China.

China provides a good setting to study the Easterlin paradox. In spite of unprecedented income growth, China's average happiness measures did not improve from 1990 to 2010 (Easterlin et al. 2012). Life satisfaction (scaled from 1, *dissatisfied*, to 10, *satisfied*) and happiness (scaled from 1, *not at all happy*, to 4, *very happy*) of the World Value Survey, happiness (scaled from 1, *very unhappy*, to 5, *very happy*) of the China Central Television (CCTV) Postcard Survey, and urban life satisfaction (scaled from 1, *very dissatisfied*, to 5, *very satisfied*) of the Horizon Research all reveal an obvious pattern of stagnant or even decreasing happiness in China during past decades. For example, the Horizon Research indicates that life satisfaction fell from 3.69 in 1997 to 3.57 in 2012 (Table A8). The CCTV survey finds that the proportion of people feeling happy or very happy declined from 54.1 percent to 48.0 percent between 2007 and 2012, while the share of people reporting they are unhappy or very unhappy rose from 7.6 percent to 11.6 percent (Figure A5).

Easterlin et al. (2012) attribute the Chinese happiness puzzle to a high

[12] Several empirical studies (Hagerty and Veenhoven 2003; Stevenson and Wolfers 2008) based on cross-country data dismiss the paradox. Drawing an updated database of 37 countries, Easterlin et al. (2010) reconfirm the paradox. Despite the controversial cross-country evidence, the paradox has been observed in a number of major economies (Tella and MacCulloch 2006; Easterlin et al. 2012).

unemployment rate due to state-owned enterprise (SOE) reforms, the dissolution of the social safety net, and rising inequality throughout the 1990s and the early 2000s. These factors may explain the temporal pattern from 1990 through 2007, but they cannot account for the decline in happiness during 2007 through 2012, as all these indicators were improved in that time. The SOE reforms were finished by the late 1990s. Since 2004, the labor market has become tighter, resulting in lower unemployment rates and more rapid increases in real wages (Zhang, Yang, and Wang 2011; Zhang et al. 2014). Along with lower unemployment rates and rising wages, the Gini coefficient for China as a whole has declined since 2008 (Xie et al. 2013). Moreover, more social safety nets have been put in place in the past decade. For example, the new rural cooperative medical insurance program has been gradually scaled up in rural areas since 2003 (Li, Xia, and Yu 2014), and the new rural pension program has been rolled out since 2009 (Chen 2015a). The evidence suggests additional factors are at play.

We echo Easterlin (1974) by finding a noticeable positive association between absolute income and happiness across individuals within a county at a given point of time (Table 3), but the association disappears over time (Table 4). However, relative income affects hedonic well-being both at a point of time and over time, confirming relative income as a plausible explanation to the Easterlin paradox.

More interesting, our results lend support to worsening air quality as an additional driving force for the observed decline in happiness. According to the World Bank, 16 of the world's top 20 most polluted cities are in China.[13] The report published by China's Ministry of Environmental Protection in June 2013 shows that about 60 percent of 325 prefecture-level cities failed to meet the Ambient Air Quality Standards (GB3095-2012) in 2012.[14] As revealed in Figure A6, air visibility declined sharply from 1997 to 2012 in China.

Based on a back-of-the-envelope calculation using the results in Table 3, a one *SD* increase in visibility lifts happiness by 0.043 (equivalent to 0.043 *SD*s). The impact is

[13] See www.cbsnews.com/news/the-most-polluted-places-on-earth/, citing "The Little Green Data Book" (World Bank, May 2007, ISBN 0-8213-6967-9).
[14] See www.zhb.gov.cn/gkml/hbb/qt/201306/t20130604_253201.htm.

rather sizable considering that a one *SD* increase in income status, one of the most important predictors of happiness, raises happiness by 0.064 (equivalent to 0.064 *SD*s). In the Horizon Research, self-reported happiness declined by 0.174 *SD*s (measured by the *SD* in 2012) from 1997 to 2012. Seen from Figure A6, the 0.95-mile or 0.268-standard-deviation (measured by the *SD* in 2012) decline in visibility during the same period accounts for 6.6 percent of the actual decrease in happiness.

Finally, we assess the money metric value of air quality. By totally differentiating equation 1 and setting $dH = 0$, we calculate the average marginal rate of substitution between air quality and absolute income $\partial Y/\partial P\big|_{dH=0} = -Y(\hat{\alpha}_1 + \hat{\alpha}_3 \ln sunshine)/(P\hat{\beta}_1)$, also known as WTP. Plugging in 1.879 for $\hat{\alpha}_1$, –0.714 for $\hat{\alpha}_3$, 0.055 for $\hat{\beta}_1$ in Table 3, and 13,264 for the mean income, 8.783 for the mean visibility, and 12.195 for the mean hours of sunshine, WTP amounts to CNY 2,562, revealing that a 0.1 *SD* improvement in air quality raises an average person's happiness by an amount worth CNY 1,041 (2,562 × 4.064 × 0.1) per year.[15] This means people are willing to pay CNY 2.9 per day per person (or $170 per year per person) for a 0.1 *SD* improvement in air quality. Our estimated WTP in a developing context is much smaller than those gauged by the US studies if measured in dollar terms. For example, Levinson (2012) estimates that an average person is willing to pay $1.80 (or CNY 11.2) per day for a 0.1 *SD* improvement in air quality compared to CNY 2.9 in China. However, if measured as the share of WTP in gross domestic product (GDP) per capita, Chinese are even willing to pay a larger share of their income, 2.7 percent (CNY 2.9 × 365 / CNY 39,544), to reduce air pollution than their U.S. counterparts (1.3 percent = $1.8 × 365 / $51,457).[16]

6. Conclusion

This paper estimates the impact of air quality on long-term life satisfaction, short-term hedonic happiness, and mental well-being by matching self-reported SWB measures in CFPS, a nationally representative survey, with air quality data from both

[15] One standard deviation of visibility is 4.064.

[16] According to the World Development Indicators released by the World Bank, in 2012 gross domestic product per capita in China and the United States are CNY 39,544 and $51,457, respectively.

internal and external sources according to the exact date of the interview. Our results show muted effects of daily air quality on overall life satisfaction, but bad air quality lowers hedonic happiness and raises the rate of depressive symptoms. In particular, people who are more concerned with environmental problems, work outdoors, earn higher incomes, reside in less polluted areas, or are in poor health are more sensitive to air quality.

Our paper shows worsening air quality may contribute to the Easterlin paradox in China. The impact of air quality on happiness is just slightly less than that of relative income, the currently accepted main contributor to the paradox. The findings suggest that the GDP-obsessed development strategy in China has not brought about more happiness. The government should go beyond GDP and include environmental indicators, such as air quality indexes, in cadres' evaluation packages.

Furthermore, evaluating a wider spectrum of the impact of air pollution is valuable to public policies. Our results indicate that the current emphasis on health-related costs understates the potential costs of pollution and therefore the benefits of reducing pollution. More scientific evidence is expected in the aspects of cognition, labor productivity, and SWB.

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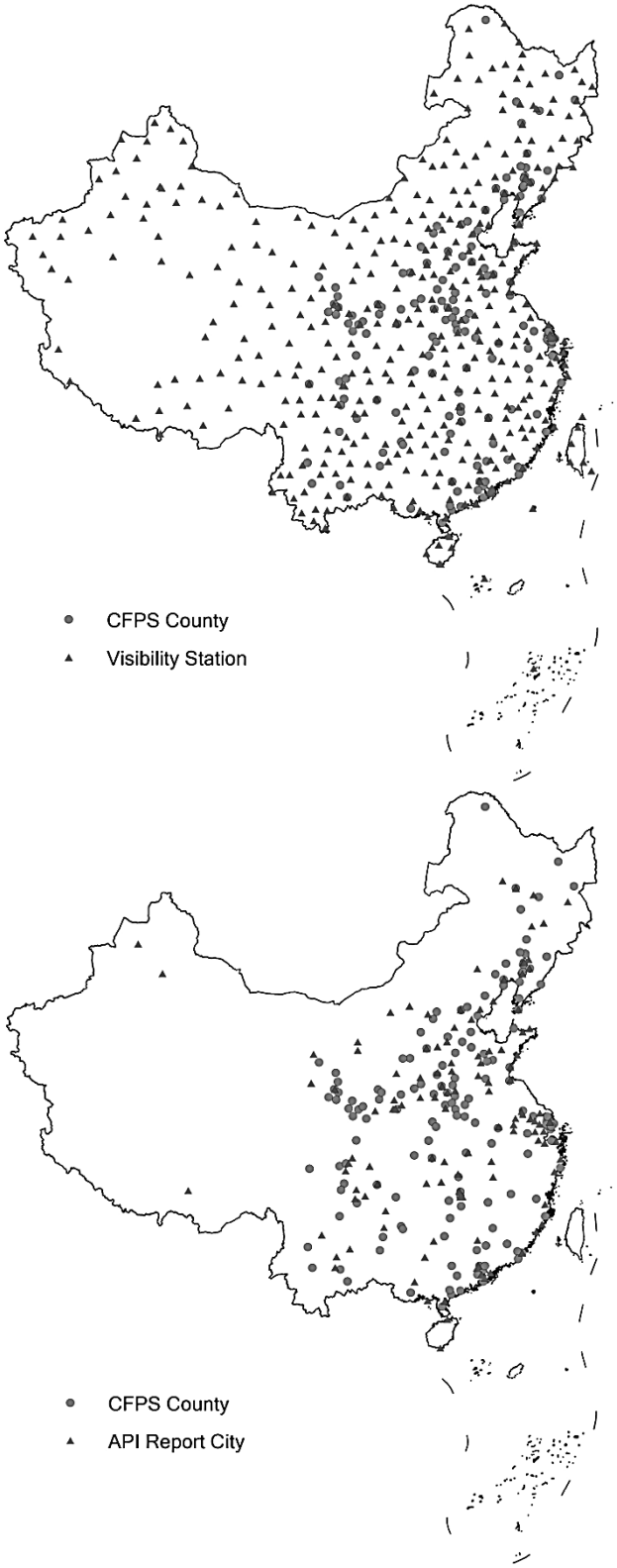
Figure 1: Distribution of China Family Panel Studies (CFPS) counties and visibility stations/air pollution index (API) report cities



Source: China Family Panel Studies; National Climatic Data Center, the National Oceanic and Atmospheric Administration; Air Quality Report published by the Ministry of Environmental Protection of China.

Note: This figure is plotted using ArcMap 10.2.

Figure 2: Relationship between visibility and subjective well-being

Source: Life satisfaction is plotted from the China Family Panel Studies (CFPS) 2010 and CFPS 2012. Hedonic happiness and CES-D score are plotted from CFPS 2012.
Note: The visibility residuals are generated by regressing visibility on county fixed effects, year and month fixed effects, and weather controls. CES-D = Center for Epidemiologic Studies Depression scale.

Table 1: Summary statistics of key variables

Variable	Definition	2010		2012	
		Mean	Standard deviation	Mean	Standard deviation
Life satisfaction	life satisfaction, ranging from 1 to 5, the higher the better	3.489	1.040	3.321	1.058
Hedonic happiness	answer to the question "I was happy," ranging from 1 to 4, the higher the better	—	—	2.811	1.000
CES-D score	the total score of the CES-D, 0–60, the lower the better	3.074	3.876	13.059	8.077
Depressive symptoms	indicator for depressive symptoms (= 1 if CES-D score ≥ 16)	—	—	0.326	0.469
Severe depression	indicator for severe depression (= 1 if CES-D score ≥ 21)	—	—	0.166	0.373
Mental well-being	the percentile of the CES-D score	0.500	0.289	0.500	0.289
Visibility	weighted visibility (miles)	8.505	4.153	8.783	4.064
API	air pollution index	64.463	35.998	58.857	21.083
Sunshine	sunshine hours	13.254	0.780	12.195	1.356
Per capita income	log form of household per capita income (in Chinese yuan)	8.620	1.056	8.990	1.128
Relative income	self-rated relative income status, the higher the better	2.203	0.970	2.232	0.977
Temperature	weighted mean temperature (10 °F)	7.389	1.109	6.693	2.211
Temp. squared	weighted mean temperature (10 °F) squared	55.830	14.770	49.681	23.073
Temp. diff.	temperature difference (daily weighted maximum-minimum, 10 °F)	1.532	0.618	1.450	0.540
Precipitation	weighted total precipitation (inches)	0.164	0.465	0.139	0.395
Wind speed	weighted maximum sustained wind speed (knots)	8.460	3.845	8.945	4.059
Bad weather	indicator for bad weather (fog, rain or drizzle, snow or ice pellets, hail, thunder, tornadoes or funnel clouds)	0.471	0.499	0.439	0.496
Age	age (÷10)	4.657	1.530	4.856	1.530
Age squared	age (÷10) squared	24.027	14.609	25.918	15.206
Male	indicator for males	0.480	0.500	0.480	0.500
Married	indicator for married status	0.842	0.365	0.841	0.365
Divorced	indicator for divorced status	0.012	0.107	0.014	0.117
Education	years of education	6.098	4.898	6.705	4.856
Unemployed	indicator for unemployed status	0.060	0.238	0.011	0.104
State employee	indicator for working in the government, public institutions, or SOEs	0.067	0.250	0.080	0.272
Party	indicator for party membership	0.077	0.267	0.084	0.278
Chronic disease	indicator for suffering from chronic diseases	0.152	0.359	0.141	0.348

Source: China Family Panel Studies 2010 and 2012.

Note: API = air pollution index; CES-D = Center for Epidemiologic Studies Depression scale; SOEs = state-owned enterprises. Dashes indicate no data for the 2010 wave of survey. The summary statistics are calculated based on the matched and balanced panel data.

Table 2: Effect of air quality (visibility versus API) on life satisfaction, longitudinal

Dependent variable	Visibility				API			
Life satisfaction	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Air quality	0.037	0.674	0.693	0.763	–0.022	–1.228	–1.329	–1.128
	(0.026)	(0.462)	(0.579)	(0.637)	(0.042)	(1.490)	(1.287)	(1.395)
Sunshine		0.566	0.773*	0.706		–1.926	–1.796	–1.207
		(0.408)	(0.463)	(0.905)		(2.419)	(2.137)	(2.536)
Air quality×Sunshine		–0.253	–0.260	–0.286		0.478	0.516	0.427
		(0.183)	(0.228)	(0.250)		(0.582)	(0.503)	(0.544)
Per capita income	0.015	0.015	0.016	0.022*	0.017	0.016	0.017	0.025*
	(0.013)	(0.013)	(0.013)	(0.012)	(0.014)	(0.014)	(0.014)	(0.013)
Relative income	0.203***	0.203***	0.204***	0.204***	0.204***	0.204***	0.205***	0.204***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.014)	(0.013)	(0.013)	(0.013)
Individual fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	No	No	Yes	Yes	No	No	Yes	Yes
Year, month, day-of-week fixed effects	No	No	No	Yes	No	No	No	Yes
Observations	27,409	27,409	27,409	27,409	24,729	24,729	24,729	24,729
Adjusted (within) *R*-squared	0.047	0.047	0.048	0.053	0.049	0.050	0.050	0.057

Source: China Family Panel Studies 2010 and 2012.

Note: The weather controls include mean temperature and its square, temperature difference (daily maximum-minimum), total precipitation, maximum sustained wind speed, and a dummy for bad weather. Demographic controls include gender, age and its square term, years of education, marital status ("married" dummy and "divorced" dummy, "never married" is the reference category), unemployment status, state employee status, party membership and chronic disease status. Robust standard errors, clustered at the county level, are presented in parentheses. API = air pollution index.

*10% significance level. **5% significance level. ***1% significance level.

Table 3: Effect of air quality (visibility versus API) on hedonic happiness, cross-sectional

Dependent variable	Visibility				API			
Hedonic happiness	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Air quality	0.107***	2.179***	2.010***	1.879***	–0.090**	–0.343	–1.621**	–1.451**
	(0.033)	(0.660)	(0.690)	(0.678)	(0.036)	(0.682)	(0.770)	(0.727)
Sunshine		2.063***	2.537***	0.629		–0.184	–1.501	–3.136**
		(0.546)	(0.736)	(1.034)		(1.223)	(1.170)	(1.269)
Air quality×Sunshine		–0.839***	–0.765***	–0.714***		0.120	0.632**	0.559*
		(0.261)	(0.273)	(0.270)		(0.271)	(0.307)	(0.291)
Per capita income	0.055***	0.056***	0.055***	0.055***	0.054***	0.054***	0.054***	0.054***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Relative income	0.065***	0.066***	0.066***	0.066***	0.066***	0.066***	0.066***	0.066***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
County fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	No	No	Yes	Yes	No	No	Yes	Yes
Month, day-of-week fixed effects	No	No	No	Yes	No	No	No	Yes
Observations	13,682	13,682	13,682	13,682	13,736	13,736	13,736	13,736
Adjusted *R*-squared	0.135	0.138	0.139	0.140	0.135	0.135	0.137	0.138

Source: China Family Panel Studies 2012.

Note: The weather controls include mean temperature and its square, temperature difference (daily maximum-minimum), total precipitation, maximum sustained wind speed, and a dummy for bad weather. Demographic controls include gender, age and its square term, years of education, marital status ("married" dummy and "divorced" dummy, "never married" is the reference category), unemployment status, state employee status, party membership and chronic disease status. Robust standard errors, clustered at the county level, are presented in parentheses. API = air pollution index.

*10% significance level. **5% significance level. ***1% significance level.

Table 4: Effect of air quality (visibility versus API) on mental well-being, longitudinal

Dependent variable	Visibility				API			
Percentile of the CES-D score	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Air quality	–0.007	–0.578*	–0.613**	–0.546**	–0.001	0.880**	0.991**	1.058**
	(0.010)	(0.296)	(0.266)	(0.263)	(0.012)	(0.366)	(0.460)	(0.461)
Sunshine		–0.335	–0.187	0.181		1.576**	1.814**	2.313***
		(0.223)	(0.230)	(0.333)		(0.643)	(0.713)	(0.776)
Air quality×Sunshine		0.225*	0.239**	0.215**		–0.342**	–0.385**	–0.416**
		(0.116)	(0.105)	(0.104)		(0.145)	(0.181)	(0.181)
Per capita income	–0.000	–0.001	–0.000	0.000	0.001	0.002	0.002	0.002
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Relative income	–0.019***	–0.019***	–0.018***	–0.018***	–0.019***	–0.019***	–0.018***	–0.018***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)
Individual fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	No	No	Yes	Yes	No	No	Yes	Yes
Year, month, day-of-week fixed effects	No	No	No	Yes	No	No	No	Yes
Observations	27,070	27,070	27,070	27,070	24,398	24,398	24,398	24,398
Adjusted (within) *R*-squared	0.012	0.019	0.021	0.029	0.011	0.017	0.019	0.028

Source: China Family Panel Studies 2010 and 2012.

Note: Lower percentile of the CES-D score indicates better mental well-being. The weather controls include mean temperature and its square, temperature difference (daily maximum-minimum), total precipitation, maximum sustained wind speed, and a dummy for bad weather. Demographic controls include gender, age and its square term, years of education, marital status ("married" dummy and "divorced" dummy, "never married" is the reference category), unemployment status, state employee status, party membership and chronic disease status. Robust standard errors, clustered at the county level, are presented in parentheses. API = air pollution index; CES-D = Center for Epidemiologic Studies Depression scale.

*10% significance level. **5% significance level. ***1% significance level.

Table 5: Effect of air quality (visibility versus API) on depressive symptoms, cross-sectional

Dependent variable	Visibility				API			
Depressive symptoms	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Air quality	–0.023	–0.733***	–0.807***	–0.750***	–0.007	0.423	0.402	0.297
	(0.016)	(0.248)	(0.264)	(0.282)	(0.017)	(0.472)	(0.477)	(0.492)
Sunshine		–0.461**	–0.502	–0.072		0.788	0.642	1.261
		(0.216)	(0.354)	(0.497)		(0.790)	(0.804)	(0.812)
Air quality×Sunshine		0.283***	0.313***	0.291**		–0.164	–0.157	–0.115
		(0.099)	(0.105)	(0.112)		(0.186)	(0.188)	(0.194)
Per capita income	–0.023***	–0.023***	–0.023***	–0.023***	–0.024***	–0.023***	–0.023***	–0.023***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Relative income	–0.037***	–0.037***	–0.037***	–0.037***	–0.037***	–0.037***	–0.037***	–0.037***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
County fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	No	No	Yes	Yes	No	No	Yes	Yes
Month, day-of-week fixed effects	No	No	No	Yes	No	No	No	Yes
Observations	13,433	13,433	13,433	13,433	13,483	13,483	13,483	13,483
Adjusted *R*-squared	0.147	0.148	0.148	0.149	0.147	0.147	0.147	0.148

Source: China Family Panel Studies 2012.

Note: The weather controls include mean temperature and its square, temperature difference (daily maximum-minimum), total precipitation, maximum sustained wind speed, and a dummy for bad weather. Demographic controls include gender, age and its square term, years of education, marital status ("married" dummy and "divorced" dummy, "never married" is the reference category), unemployment status, state employee status, party membership and chronic disease status. Robust standard errors, clustered at the county level, are presented in parentheses. API = air pollution index.

**5% significance level. ***1% significance level.

Table 6: Effect of air quality (visibility versus API) on severe depression, cross-sectional

Dependent variable	Visibility				API			
Severe depression	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Air quality	0.005	–0.344**	–0.376**	–0.330**	–0.019	0.249	0.325	0.255
	(0.012)	(0.143)	(0.145)	(0.145)	(0.012)	(0.258)	(0.284)	(0.293)
Sunshine		–0.145	–0.210	–0.025		0.540	0.523	0.771
		(0.133)	(0.213)	(0.321)		(0.434)	(0.461)	(0.472)
Air quality×Sunshine		0.137**	0.149**	0.131**		–0.099	–0.130	–0.101
		(0.059)	(0.060)	(0.060)		(0.102)	(0.113)	(0.117)
Per capita income	–0.015***	–0.015***	–0.015***	–0.015***	–0.016***	–0.015***	–0.015***	–0.015***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Relative income	–0.027***	–0.027***	–0.027***	–0.027***	–0.027***	–0.027***	–0.027***	–0.027***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
County fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	No	No	Yes	Yes	No	No	Yes	Yes
Month, day-of-week fixed effects	No	No	No	Yes	No	No	No	Yes
Observations	13,433	13,433	13,433	13,433	13,483	13,483	13,483	13,483
Adjusted *R*-squared	0.113	0.115	0.115	0.115	0.113	0.114	0.114	0.115

Source: China Family Panel Studies 2012.

Note: The weather controls include mean temperature and its square, temperature difference (daily maximum-minimum), total precipitation, maximum sustained wind speed, and a dummy for bad weather. Demographic controls include gender, age and its square term, years of education, marital status ("married" dummy and "divorced" dummy, "never married" is the reference category), unemployment status, state employee status, party membership and chronic disease status. Robust standard errors, clustered at the county level, are presented in parentheses. API = air pollution index.

**5% significance level. ***1% significance level.

Table 7: Deviation-from-the-mean effect of air quality (visibility versus API) on life satisfaction

A. Visibility				
Dependent variable	7-day deviation	30-day deviation	90-day deviation	365-day deviation
Life satisfaction	(1)	(2)	(3)	(4)
$\ln P_t - \frac{1}{k}\sum_{i=0}^{k-1} \ln P_{t-i}$	0.000	0.005	0.022	0.016
	(0.031)	(0.030)	(0.032)	(0.036)
Per capita income	0.022*	0.022*	0.022*	0.022*
	(0.012)	(0.012)	(0.012)	(0.012)
Relative income	0.204***	0.205***	0.206***	0.205***
	(0.012)	(0.012)	(0.012)	(0.012)
Observations	27,408	27,392	27,332	26,674
Adjusted (within) *R*-squared	0.052	0.052	0.052	0.052
B. API				
Dependent variable	7-day deviation	30-day deviation	90-day deviation	365-day deviation
Life satisfaction	(5)	(6)	(7)	(8)
$\ln P_t - \frac{1}{k}\sum_{i=0}^{k-1} \ln P_{t-i}$	–0.015	–0.016	–0.017	–0.015
	(0.050)	(0.051)	(0.051)	(0.051)
Per capita income	0.026*	0.026*	0.026*	0.026*
	(0.013)	(0.013)	(0.013)	(0.013)
Relative income	0.203***	0.203***	0.203***	0.203***
	(0.013)	(0.013)	(0.013)	(0.013)
Observations	24,729	24,729	24,729	24,699
Adjusted (within) *R*-squared	0.057	0.057	0.057	0.056

Source: China Family Panel Studies 2010 and 2012.

Note: $\frac{1}{k}\sum_{i=0}^{k-1} \ln P_{t-i}$ indicates the mean of the pollution level (visibility/API) in the past k days, where k equals 7, 30, 90, and 365, respectively. Other covariates and fixed effects are the same as those in column (4) of Table 2. Robust standard errors, clustered at the county level, are presented in parentheses. API = air pollution index.
*10% significance level. ***1% significance level.

Table 8: Heterogeneity test of air quality effect, by gender and age

A. Hedonic happiness					
Dependent variable	Gender		Age		
Hedonic happiness	Male	Female	Young (16–39)	Middle (40–59)	Old (60 and older)
	(1)	(2)	(3)	(4)	(5)
Dep. Var. mean	*2.911*	*2.796*	*2.918*	*2.830*	*2.830*
Visibility	1.353	2.303***	1.378*	1.875**	1.935*
	(0.823)	(0.665)	(0.826)	(0.919)	(1.125)
Sunshine	–0.285	1.381	–0.056	0.880	–0.632
	(1.233)	(1.117)	(1.241)	(1.442)	(1.834)
Visibility×Sunshine	–0.517	–0.875***	–0.489	–0.713*	–0.737
	(0.329)	(0.268)	(0.335)	(0.366)	(0.445)
Per capita income	0.049***	0.062***	0.013	0.067***	0.080***
	(0.014)	(0.013)	(0.016)	(0.014)	(0.022)
Relative income	0.069***	0.062***	0.046**	0.075***	0.068***
	(0.015)	(0.013)	(0.019)	(0.015)	(0.019)
Observations	6,699	6,983	3,507	6,599	3,576
Adj. *R*-squared	0.132	0.139	0.151	0.134	0.153

B. Mental well-being					
Dependent variable	Gender		Age		
Percentile of the CES-D score	Male	Female	Young (16–39)	Middle (40–59)	Old (60 and older)
	(1)	(2)	(3)	(4)	(5)
Dep. Var. mean	*0.449*	*0.510*	*0.469*	*0.483*	*0.485*
Visibility	–0.506*	–0.605**	–0.264	–0.577**	–0.812**
	(0.263)	(0.289)	(0.426)	(0.262)	(0.335)
Sunshine	0.168	0.191	0.689	0.148	–0.912*
	(0.366)	(0.347)	(0.468)	(0.353)	(0.476)
Visibility×Sunshine	0.198*	0.238**	0.096	0.230**	0.326**
	(0.104)	(0.114)	(0.168)	(0.103)	(0.131)
Per capita income	–0.002	0.003	–0.000	–0.005	0.008
	(0.004)	(0.004)	(0.006)	(0.005)	(0.006)
Relative income	–0.019***	–0.018***	–0.015**	–0.021***	–0.015***
	(0.004)	(0.004)	(0.006)	(0.004)	(0.006)
Observations	13,304	13,766	7,550	13,067	6,453
Adj. (within) *R*-squared	0.038	0.030	0.051	0.030	0.022

Source: Panel A is from the China Family Panel Studies (CFPS) 2012, and panel B is from CFPS 2010 and CFPS 2012.

Note: Lower percentile of the CES-D score indicates better mental well-being. In panel A, other covariates and fixed effects are the same as those in column (4) of Table 3. In panel B, other covariates and fixed effects are the same as those in column (4) of Table 4. Robust standard errors, clustered at the county level, are presented in parentheses. CES-D = Center for Epidemiologic Studies Depression scale. Adj. = Adjusted; Dep. Var. = Dependent variable.

*10% significance level. **5% significance level. ***1% significance level.

Table 9: Heterogeneity test of air quality effect, by income levels

A. Hedonic happiness				
Dependent variable	0–25%	25–50%	50–75%	75–100%
Hedonic happiness	(1)	(2)	(3)	(4)
Dep. Var. mean	*2.697*	*2.795*	*2.892*	*2.990*
Visibility	2.276	1.724**	1.178	2.963***
	(1.522)	(0.866)	(0.789)	(0.847)
Sunshine	1.898	1.213	–0.430	1.852
	(2.496)	(1.487)	(1.585)	(1.375)
Visibility×Sunshine	–0.883	–0.626*	–0.432	–1.147***
	(0.608)	(0.351)	(0.309)	(0.335)
Per capita income	0.012	0.077	0.060	0.094**
	(0.018)	(0.105)	(0.113)	(0.045)
Relative income	0.096***	0.065***	0.033	0.050***
	(0.020)	(0.019)	(0.020)	(0.019)
Observations	3,107	3,259	3,428	3,888
Adj. *R*-squared	0.145	0.166	0.124	0.112
B. Mental well-being				
Dependent variable	0–25%	25–50%	50–75%	75–100%
Percentile of the CES-D score	(1)	(2)	(3)	(4)
Dep. Var. mean	*0.547*	*0.502*	*0.468*	*0.421*
Visibility	–0.681	–0.646**	–0.646	–1.200***
	(0.525)	(0.320)	(0.410)	(0.416)
Sunshine	–0.436	0.173	0.793	–0.344
	(0.724)	(0.594)	(0.527)	(0.490)
Visibility×Sunshine	0.268	0.255**	0.246	0.476***
	(0.207)	(0.128)	(0.164)	(0.164)
Per capita income	0.012	–0.021	–0.034	–0.030**
	(0.009)	(0.040)	(0.052)	(0.014)
Relative income	–0.029***	–0.021**	–0.024***	–0.001
	(0.008)	(0.009)	(0.009)	(0.007)
Observations	5,969	6,490	6,727	7,884
Adj. (within) *R*-squared	0.052	0.058	0.076	0.066

Source: Panel A is from the China Family Panel Studies (CFPS) 2012, and panel B is from CFPS 2010 and CFPS 2012.

Note: Lower percentile of the CES-D score indicates better mental well-being. In panel A, other covariates and fixed effects are the same as those in column (4) of Table 3. In panel B, other covariates and fixed effects are the same as those in column (4) of Table 4. Robust standard errors, clustered at the county level, are presented in parentheses. CES-D = Center for Epidemiologic Studies Depression scale. Adj. = Adjusted; Dep. Var. = Dependent variable.

*10% significance level. **5% significance level. ***1% significance level.

Table 10: Heterogeneity test of air quality effect, by pollution attitude and workplace

A. Hedonic happiness				
Dependent variable	Pollution attitude		Workplace	
Hedonic happiness	Careless	Critical	Indoors	Outdoors
	(1)	(2)	(3)	(4)
Dep. Var. mean	*2.838*	*2.888*	*2.962*	*2.818*
Visibility	1.541*	2.127***	0.028	2.187**
	(0.832)	(0.642)	(0.813)	(1.034)
Sunshine	1.655	–0.253	0.453	0.399
	(1.435)	(1.111)	(1.505)	(1.529)
Visibility×Sunshine	–0.595*	–0.800***	0.025	–0.854**
	(0.335)	(0.256)	(0.334)	(0.412)
Per capita income	0.050***	0.057***	0.059***	0.041***
	(0.014)	(0.012)	(0.019)	(0.011)
Relative income	0.071***	0.054***	0.043**	0.069***
	(0.013)	(0.014)	(0.019)	(0.013)
Observations	6,260	6,878	3,718	6,242
Adj. *R*-squared	0.141	0.136	0.123	0.145
B. Mental well-being				
Dependent variable	Pollution attitude		Workplace	
Percentile of the	Careless	Critical	Indoors	Outdoors
CES-D score	(1)	(2)	(3)	(4)
Dep. Var. mean	*0.484*	*0.470*	*0.445*	*0.485*
Visibility	–0.377	–0.687**	–0.648**	–0.467**
	(0.263)	(0.301)	(0.307)	(0.203)
Sunshine	0.340	0.105	0.453	0.373
	(0.351)	(0.367)	(0.502)	(0.338)
Visibility×Sunshine	0.146	0.273**	0.245**	0.189**
	(0.103)	(0.119)	(0.122)	(0.080)
Per capita income	–0.001	–0.000	–0.011	–0.005
	(0.005)	(0.005)	(0.009)	(0.006)
Relative income	–0.019***	–0.015***	–0.023**	–0.023***
	(0.004)	(0.004)	(0.009)	(0.005)
Observations	12,354	13,626	6,175	10,220
Adj. (within) *R*-squared	0.027	0.033	0.083	0.037

Source: Panel A is from the China Family Panel Studies (CFPS) 2012, and panel B is from CFPS 2010 and CFPS 2012.

Note: Lower percentile of the CES-D score indicates better mental well-being. In panel A, other covariates and fixed effects are the same as those in column (4) of Table 3. In panel B, other covariates and fixed effects are the same as those in column (4) of Table 4. Robust standard errors, clustered at the county level, are presented in parentheses. CES-D = Center for Epidemiologic Studies Depression scale. Adj. = Adjusted; Dep. Var. = Dependent variable.
*10% significance level. **5% significance level. ***1% significance level.

Table 11: Heterogeneity test of air quality effect, by pollution level and health

A. Hedonic happiness				
Dependent variable	Local yearly pollution level		Chronic disease	
Hedonic happiness	Polluted	Less polluted	Yes	No
	(1)	(2)	(3)	(4)
Dep. Var. mean	*2.882*	*2.833*	*2.741*	*2.872*
Visibility	1.306	2.193***	2.922**	1.683**
	(1.657)	(0.660)	(1.271)	(0.751)
Sunshine	0.488	0.472	4.289*	0.059
	(1.667)	(1.264)	(2.404)	(1.161)
Visibility×Sunshine	–0.485	–0.845***	–1.111**	–0.641**
	(0.655)	(0.265)	(0.508)	(0.300)
Per capita income	0.068***	0.045***	0.055**	0.056***
	(0.016)	(0.012)	(0.023)	(0.011)
Relative income	0.074***	0.055***	0.085***	0.063***
	(0.015)	(0.012)	(0.026)	(0.010)
Observations	6,598	6,658	2,005	11,677
Adj. *R*-squared	0.106	0.173	0.120	0.144

B. Mental well-being				
Dependent variable	Local yearly pollution level		Chronic disease	
Percentile of the CES-D score	Polluted	Less polluted	Yes	No
	(1)	(2)	(3)	(4)
Dep. Var. mean	*0.456*	*0.500*	*0.572*	*0.464*
Visibility	–0.356	–0.944**	–1.050**	–0.382
	(0.269)	(0.435)	(0.406)	(0.252)
Sunshine	0.356	0.040	–1.382**	0.409
	(0.408)	(0.525)	(0.603)	(0.323)
Visibility×Sunshine	0.137	0.375**	0.402**	0.148
	(0.106)	(0.172)	(0.160)	(0.099)
Per capita income	0.002	–0.000	–0.007	0.001
	(0.005)	(0.005)	(0.012)	(0.004)
Relative income	–0.013**	–0.020***	–0.018	–0.015***
	(0.005)	(0.004)	(0.011)	(0.004)
Observations	13,132	13,228	4,031	23,039
Adj. (within) *R*-squared	0.023	0.050	0.088	0.022

Source: Panel A is from the China Family Panel Studies (CFPS) 2012, and panel B is from CFPS 2010 and CFPS 2012.

Note: Lower percentile of the CES-D score indicates better mental well-being. In panel A, other covariates and fixed effects are the same as those in column (4) of Table 3. In panel B, other covariates and fixed effects are the same as those in column (4) of Table 4. Robust standard errors, clustered at the county level, are presented in parentheses. CES-D = Center for Epidemiologic Studies Depression scale. Adj. = Adjusted; Dep. Var. = Dependent variable.
*10% significance level. **5% significance level. ***1% significance level.

Table 12: Heterogeneity test of air quality effect, by education years

A. Hedonic happiness				
Dependent variable	Visibility		API	
Hedonic happiness	Less educated (education ≤ 6)	More educated (education ≥ 9)	Less educated (education ≤ 6)	More educated (education ≥ 9)
	(1)	(2)	(3)	(4)
Dep. Var. mean	*2.711*	*2.976*	*2.713*	*2.976*
Air quality	1.546	2.175***	0.326	–2.320***
	(0.941)	(0.677)	(1.278)	(0.706)
Sunshine	0.951	–0.111	0.347	–5.494***
	(1.908)	(1.064)	(2.192)	(1.323)
Air quality×Sunshine	–0.562	–0.837***	–0.139	0.891***
	(0.374)	(0.271)	(0.507)	(0.287)
Per capita income	0.068***	0.049***	0.066***	0.048***
	(0.013)	(0.013)	(0.013)	(0.013)
Relative income	0.074***	0.051***	0.075***	0.049***
	(0.013)	(0.015)	(0.013)	(0.014)
Observations	5,933	6,615	5,972	6,626
Adj. *R*-squared	0.154	0.112	0.151	0.111

B. Mental well-being				
Dependent variable	Visibility		API	
Percentile of the CES-D score	Less educated (education ≤ 6)	More educated (education ≥ 9)	Less educated (education ≤ 6)	More educated (education ≥ 9)
	(1)	(2)	(3)	(4)
Dep. Var. mean	*0.527*	*0.435*	*0.529*	*0.432*
Air quality	–0.510*	–0.659**	0.788*	1.198**
	(0.268)	(0.303)	(0.466)	(0.537)
Sunshine	–0.101	0.129	1.587*	2.634***
	(0.342)	(0.421)	(0.844)	(0.843)
Air quality×Sunshine	0.199*	0.260**	–0.306*	–0.472**
	(0.106)	(0.119)	(0.183)	(0.212)
Per capita income	0.003	–0.001	0.007	–0.001
	(0.005)	(0.005)	(0.006)	(0.005)
Relative income	–0.018***	–0.015***	–0.016***	–0.014***
	(0.004)	(0.004)	(0.005)	(0.005)
Observations	12,467	12,751	11,138	11,570
Adj. (within) *R*-squared	0.024	0.042	0.022	0.042

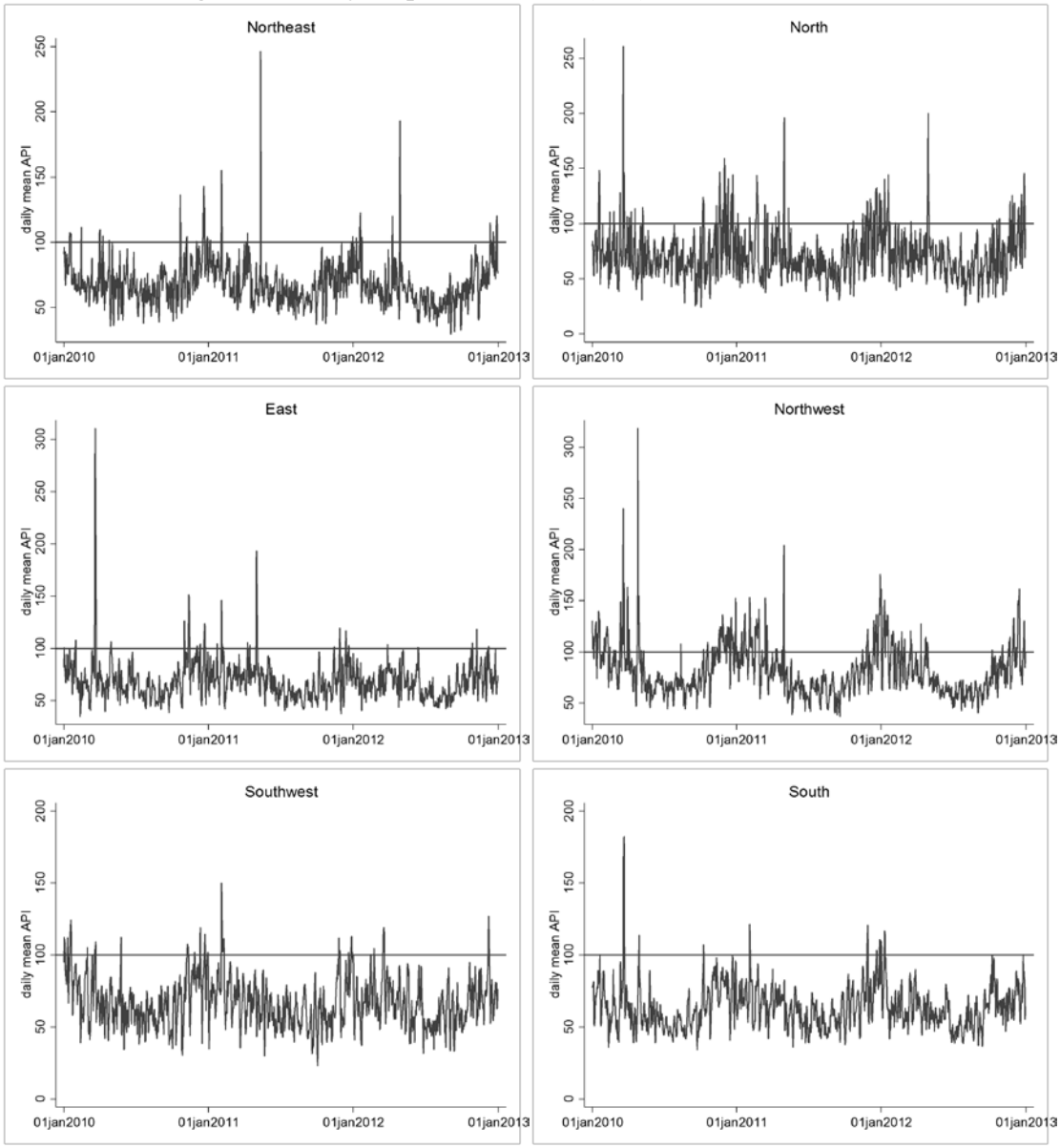
Source: Panel A is from the China Family Panel Studies (CFPS) 2012, and panel B is from CFPS 2010 and CFPS 2012.

Note: Lower percentile of the CES-D score indicates better mental well-being. In panel A, other covariates and fixed effects are the same as those in column (4) of Table 3. In panel B, other covariates and fixed effects are the same as those in column (4) of Table 4. Robust standard errors, clustered at the county level, are presented in parentheses. API = air pollution index; CES-D = Center for Epidemiologic Studies Depression scale. Adj. = Adjusted; Dep. Var. = Dependent variable.

*10% significance level. **5% significance level. ***1% significance level.

Online Appendix A: Supplementary Figures and Tables

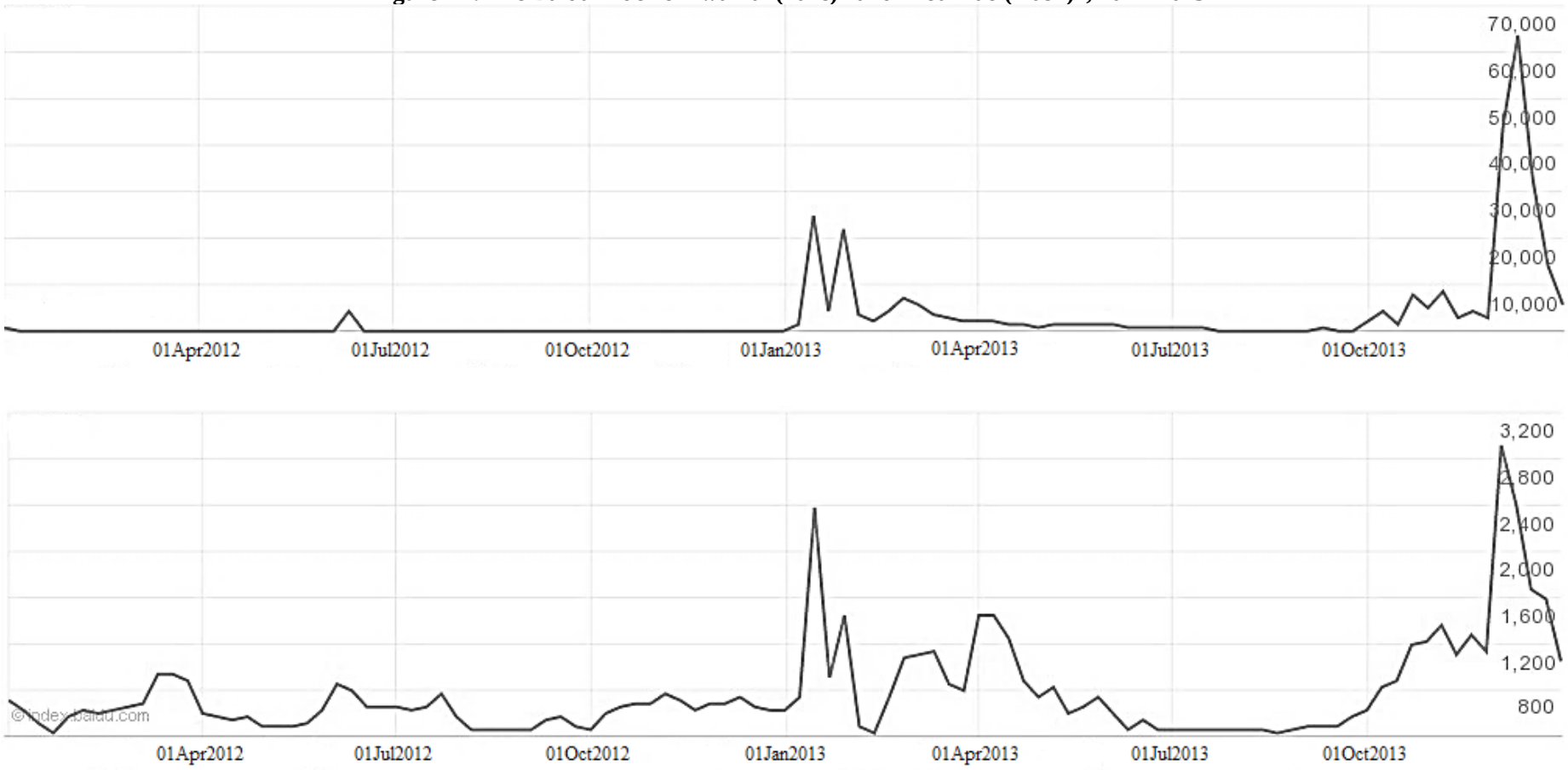
Figure A1: Daily air pollution index (API) in China, 2010–2012



Source: Air quality daily report published by the Ministry of Environmental Protection of the People's Republic of China.

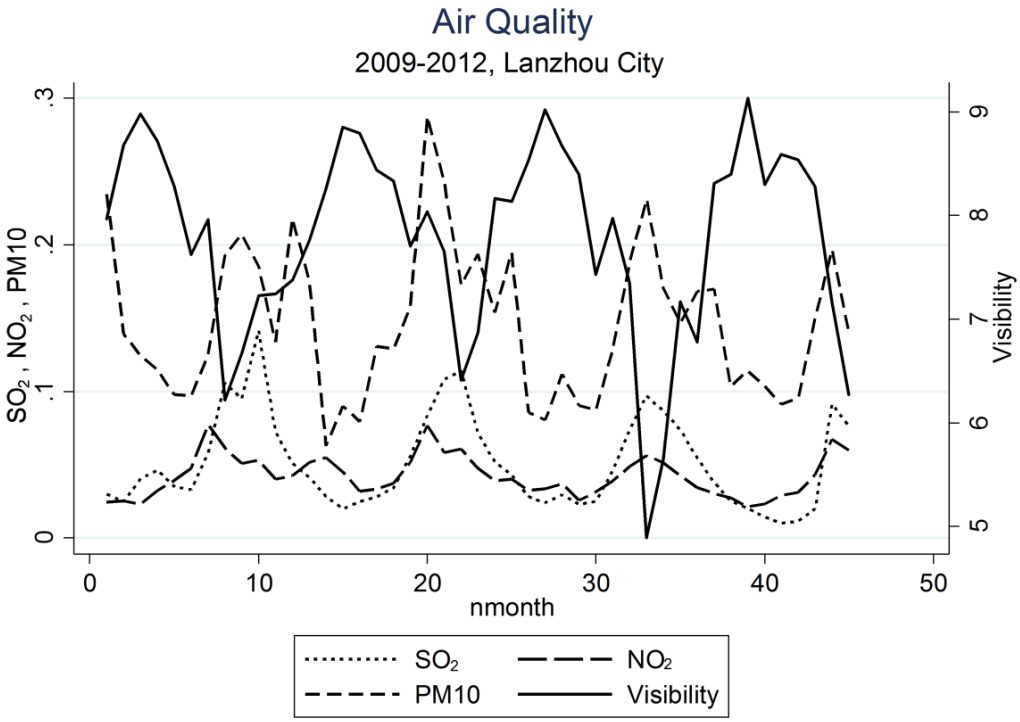
Note: The daily mean API is calculated by the weighted average values of all the API report cities within the region, where the weight is the yearly population in each city. The US National Ambient Air Quality Standards of fine particulate matter smaller than 10 micrometers is 0.15 mg/m^3, which corresponds to 100 of API in China. Northeast China includes Heilongjiang, Jilin, and Liaoning. North China includes Beijing, Hebei, Inner Mongolia, Shanxi, and Tianjin. East China includes Anhui, Fujian, Jiangsu, Jiangxi, Shandong, Shanghai, and Zhejiang. Northwest China includes Gansu, Ningxia, Qinghai, Shanxi, and Xinjiang. Southwest China includes Guizhou, Sichuan, Tibet, Yunnan, and Chongqing. South China includes Guangdong, Guangxi, Hainan, Henan, Hubei, and Hunan. jan = January.

Figure A2: The Baidu Index of "wumai (haze)" and "kouzhao (mask)", 2012–2013



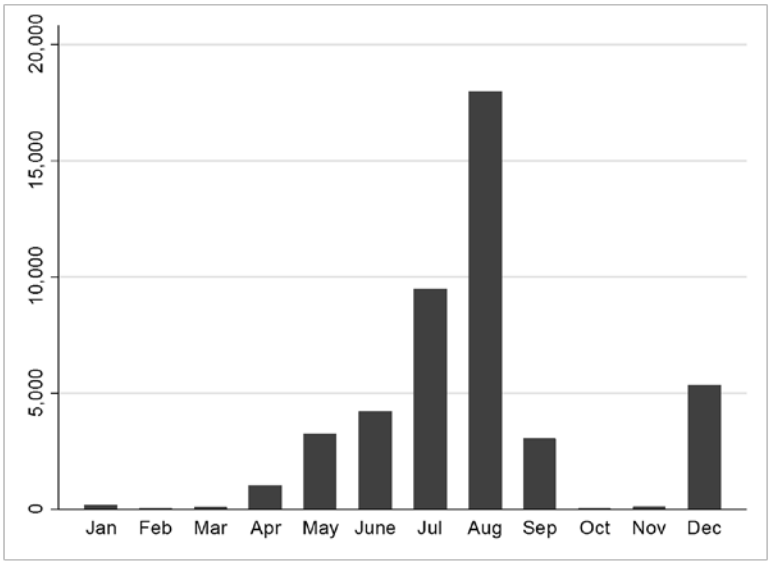
Source: http://index.baidu.com/.
Note: Apr=April; Jan=January; Jul=July; Oct=October.

Figure A3: Relation between visibility and PM10, SO2, and NO2



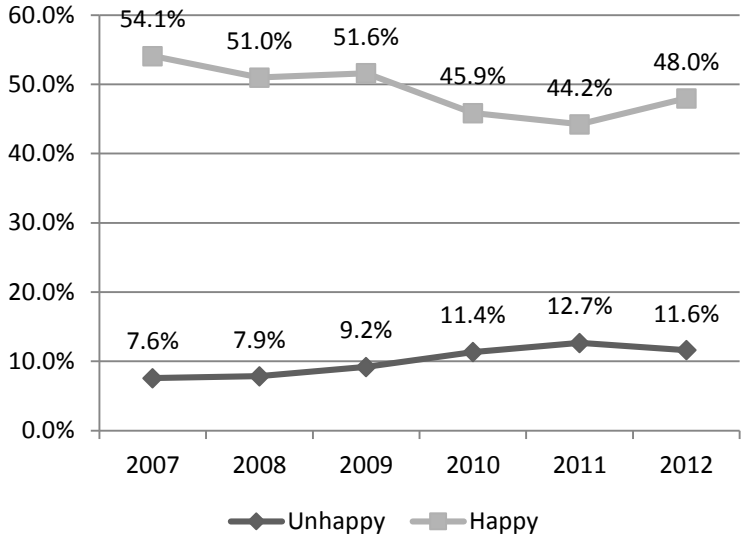
Source: Visibility data are monitored by the National Oceanic and Atmospheric Administration. NO_2, SO_2, and PM10 are from Chinese official air quality statistics.
Note: Jan = January; Mar = March; NO_2 = nitrogen dioxide; Nov = November; PM10 = fine particulate matter smaller than 10 micrometers; Sep = September; SO_2 = sulfur dioxide.

Figure A4: Interview date distribution, 2010 and 2012



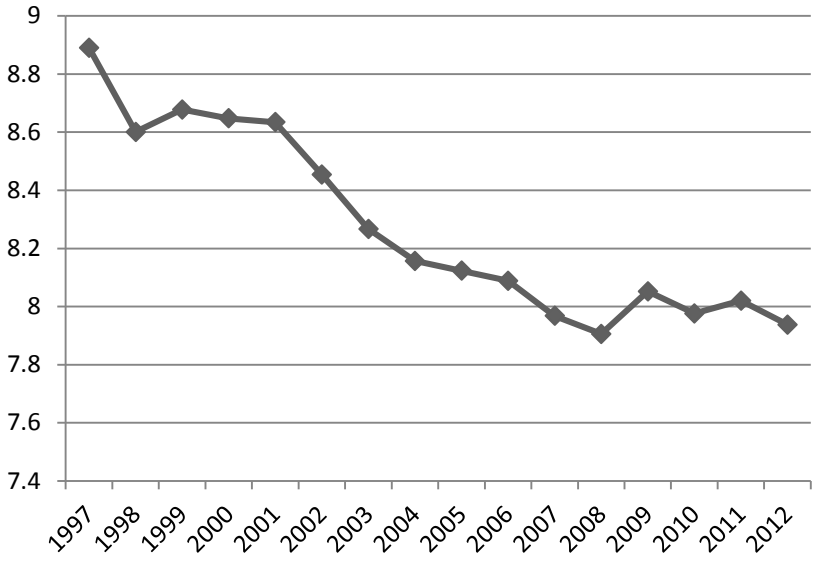
Source: China Family Panel Studies 2010 and 2012.
Note: Apr = April; Aug = August; Dec = December; Feb = February; Jan = January; Jul = July; Mar = March; Nov = November; Oct = October; Sep = September.

Figure A5: Happiness Trend according to the China Central Television (CCTV) Postcard Survey, 2007–2012



Source: CCTV Postcard Survey.

Figure A6: Visibility Trend in China, 1997–2012



Source: National Climatic Data Center under the National Oceanic and Atmospheric Administration.
Note: The yearly average visibility is calculated by the weighted average values of all the monitor stations in China where the weights are equal to the population at the county level.

Table A1: Effect of air quality (visibility versus API) on life satisfaction, longitudinal

Dependent variable	Visibility				API			
Life satisfaction	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Air quality	0.037	0.674	0.693	0.763	–0.022	–1.228	–1.329	–1.128
	(0.026)	(0.462)	(0.579)	(0.637)	(0.042)	(1.490)	(1.287)	(1.395)
Sunshine		0.566	0.773*	0.706		–1.926	–1.796	–1.207
		(0.408)	(0.463)	(0.905)		(2.419)	(2.137)	(2.536)
Air quality×Sunshine		–0.253	–0.260	–0.286		0.478	0.516	0.427
		(0.183)	(0.228)	(0.250)		(0.582)	(0.503)	(0.544)
Household per capita income	0.015	0.015	0.016	0.022*	0.017	0.016	0.017	0.025*
	(0.013)	(0.013)	(0.013)	(0.012)	(0.014)	(0.014)	(0.014)	(0.013)
Relative income	0.203***	0.203***	0.204***	0.204***	0.204***	0.204***	0.205***	0.204***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.014)	(0.013)	(0.013)	(0.013)
Age (÷10) squared	–0.070***	–0.067***	–0.062***	0.026	–0.077***	–0.073***	–0.070***	0.027
	(0.011)	(0.011)	(0.012)	(0.020)	(0.012)	(0.013)	(0.014)	(0.022)
Married	0.044	0.045	0.051	0.114*	0.021	0.017	0.024	0.094
	(0.065)	(0.065)	(0.065)	(0.066)	(0.076)	(0.074)	(0.074)	(0.074)
Divorced	–0.317**	–0.312**	–0.303**	–0.245*	–0.384**	–0.380**	–0.369**	–0.296*
	(0.142)	(0.142)	(0.142)	(0.145)	(0.154)	(0.153)	(0.153)	(0.158)
Education	–0.000	–0.000	–0.000	0.004	–0.001	–0.001	–0.000	0.004
	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)
Unemployed	–0.003	–0.004	–0.006	–0.041	–0.022	–0.029	–0.031	–0.070
	(0.061)	(0.061)	(0.061)	(0.059)	(0.071)	(0.069)	(0.070)	(0.066)
State employee	0.026	0.026	0.029	0.033	0.039	0.039	0.042	0.044
	(0.048)	(0.048)	(0.047)	(0.048)	(0.055)	(0.054)	(0.054)	(0.053)
Party	0.050	0.049	0.048	0.064	0.091	0.092	0.089	0.106
	(0.068)	(0.068)	(0.068)	(0.067)	(0.071)	(0.072)	(0.071)	(0.071)
Chronic disease	–0.091***	–0.091***	–0.092***	–0.092***	–0.095***	–0.096***	–0.097***	–0.097***
	(0.026)	(0.026)	(0.026)	(0.026)	(0.030)	(0.031)	(0.030)	(0.030)
Individual fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	No	No	Yes	Yes	No	No	Yes	Yes
Year, month, day-of-week fixed effects	No	No	No	Yes	No	No	No	Yes
Observations	27,409	27,409	27,409	27,409	24,729	24,729	24,729	24,729
Adjusted (within) *R*-squared	0.047	0.047	0.048	0.053	0.049	0.050	0.050	0.057

Source: China Family Panel Studies 2010 and 2012.

Note: This table presents the full results in Table 2. The weather controls include mean temperature and its square, temperature difference (daily maximum-minimum), total precipitation, maximum sustained wind speed, and a dummy for bad weather. Robust standard errors, clustered at the county level, are presented in parentheses. API = air pollution index.

*10% significance level. **5% significance level. ***1% significance level.

Table A2: Effect of air quality (visibility versus API) on hedonic happiness, cross-sectional

Dependent variable	Visibility				API			
Hedonic happiness	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Air quality	0.107***	2.179***	2.010***	1.879***	–0.090**	–0.343	–1.621**	–1.451**
	(0.033)	(0.660)	(0.690)	(0.678)	(0.036)	(0.682)	(0.770)	(0.727)
Sunshine		2.063***	2.537***	0.629		–0.184	–1.501	–3.136**
		(0.546)	(0.736)	(1.034)		(1.223)	(1.170)	(1.269)
Air quality×Sunshine		–0.839***	–0.765***	–0.714***		0.120	0.632**	0.559*
		(0.261)	(0.273)	(0.270)		(0.271)	(0.307)	(0.291)
Household per capita income	0.055***	0.056***	0.055***	0.055***	0.054***	0.054***	0.054***	0.054***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Relative income	0.065***	0.066***	0.066***	0.066***	0.066***	0.066***	0.066***	0.066***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Age (÷10)	–0.078**	–0.078**	–0.075**	–0.073**	–0.080**	–0.081**	–0.080**	–0.077**
	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)
Age (÷10) squared	0.007*	0.006*	0.006*	0.006*	0.007*	0.007*	0.007*	0.006*
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Male	0.071***	0.073***	0.074***	0.074***	0.071***	0.072***	0.073***	0.074***
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
Married	0.108***	0.105***	0.104***	0.102***	0.110***	0.109***	0.107***	0.105***
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)
Divorced	–0.107*	–0.110*	–0.112*	–0.114*	–0.103*	–0.104*	–0.107*	–0.109*
	(0.059)	(0.059)	(0.059)	(0.059)	(0.059)	(0.059)	(0.059)	(0.059)
Education	0.015***	0.015***	0.014***	0.014***	0.015***	0.015***	0.015***	0.014***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Unemployed	–0.085	–0.091	–0.095	–0.098	–0.089	–0.084	–0.094	–0.098
	(0.080)	(0.080)	(0.080)	(0.080)	(0.080)	(0.081)	(0.080)	(0.080)
State employee	–0.035	–0.034	–0.032	–0.034	–0.036	–0.034	–0.031	–0.032
	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)
Party	0.113***	0.113***	0.114***	0.113***	0.112***	0.112***	0.113***	0.112***
	(0.031)	(0.031)	(0.031)	(0.031)	(0.031)	(0.031)	(0.031)	(0.031)
Chronic disease	–0.122***	–0.125***	–0.126***	–0.125***	–0.121***	–0.122***	–0.123***	–0.123***
	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)
County fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	No	No	Yes	Yes	No	No	Yes	Yes
Month, day-of-week fixed effects	No	No	No	Yes	No	No	No	Yes
Observations	13,682	13,682	13,682	13,682	13,736	13,736	13,736	13,736
Adjusted *R*-squared	0.135	0.138	0.139	0.140	0.135	0.135	0.137	0.138

Source: China Family Panel Studies 2012.

Note: This table presents the full results in Table 3. The weather controls include mean temperature and its square, temperature difference (daily maximum-minimum), total precipitation, maximum sustained wind speed, and a dummy for bad weather. Robust standard errors, clustered at the county level, are presented in parentheses. API = air pollution index.

*10% significance level. **5% significance level. ***1% significance level.

Table A3: Effect of air quality (visibility versus API) on mental well-being, longitudinal

Dependent variable	Visibility				API			
Percentile of the CES-D score	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Air quality	–0.007	–0.578*	–0.613**	–0.546**	–0.001	0.880**	0.991**	1.058**
	(0.010)	(0.296)	(0.266)	(0.263)	(0.012)	(0.366)	(0.460)	(0.461)
Sunshine		–0.335	–0.187	0.181		1.576**	1.814**	2.313***
		(0.223)	(0.230)	(0.333)		(0.643)	(0.713)	(0.776)
Air quality×Sunshine		0.225*	0.239**	0.215**		–0.342**	–0.385**	–0.416**
		(0.116)	(0.105)	(0.104)		(0.145)	(0.181)	(0.181)
Household per capita income	–0.000	–0.001	–0.000	0.000	0.001	0.002	0.002	0.002
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Relative income	–0.019***	–0.019***	–0.018***	–0.018***	–0.019***	–0.019***	–0.018***	–0.018***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)
Age (÷10) squared	0.001	0.005	0.009**	0.035***	–0.000	0.006	0.009*	0.031***
	(0.004)	(0.004)	(0.005)	(0.008)	(0.005)	(0.005)	(0.005)	(0.009)
Married	–0.094***	–0.092***	–0.089***	–0.072***	–0.087***	–0.080***	–0.078***	–0.063***
	(0.017)	(0.017)	(0.017)	(0.016)	(0.018)	(0.017)	(0.017)	(0.018)
Divorced	–0.004	0.001	0.005	0.025	–0.020	–0.012	–0.009	0.009
	(0.038)	(0.038)	(0.037)	(0.038)	(0.040)	(0.039)	(0.039)	(0.041)
Education	–0.000	–0.000	–0.000	0.000	–0.002	–0.002	–0.002	–0.002
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Unemployed	0.043***	0.037***	0.037**	0.028**	0.046***	0.043***	0.043***	0.035**
	(0.014)	(0.014)	(0.014)	(0.014)	(0.016)	(0.015)	(0.015)	(0.015)
State employee	–0.003	–0.003	–0.002	–0.000	–0.002	–0.001	–0.001	0.002
	(0.012)	(0.012)	(0.012)	(0.012)	(0.013)	(0.013)	(0.013)	(0.013)
Party	–0.023	–0.022	–0.023	–0.018	–0.004	–0.006	–0.004	–0.001
	(0.021)	(0.020)	(0.020)	(0.020)	(0.024)	(0.024)	(0.023)	(0.023)
Chronic disease	0.045***	0.044***	0.044***	0.044***	0.038***	0.037***	0.037***	0.037***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)	(0.009)
Individual fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	No	No	Yes	Yes	No	No	Yes	Yes
Year, month, day-of-week fixed effects	No	No	No	Yes	No	No	No	Yes
Observations	27,070	27,070	27,070	27,070	24,398	24,398	24,398	24,398
Adjusted (within) *R*-squared	0.012	0.019	0.021	0.029	0.011	0.017	0.019	0.028

Source: China Family Panel Studies 2010 and 2012.

Note: This table presents the full results in Table 4. Lower percentile of the CES-D score indicates better mental well-being. The weather controls include mean temperature and its square, temperature difference (daily maximum-minimum), total precipitation, maximum sustained wind speed, and a dummy for bad weather. Robust standard errors, clustered at the county level, are presented in parentheses. API = air pollution index; CES-D = Center for Epidemiologic Studies Depression scale.

*10% significance level. **5% significance level. ***1% significance level.

Table A4: Effect of air quality (visibility versus API) on depressive symptoms, cross-sectional

Dependent variable	Visibility				API			
Depressive symptoms	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Air quality	–0.023	–0.733***	–0.807***	–0.750***	–0.007	0.423	0.402	0.297
	(0.016)	(0.248)	(0.264)	(0.282)	(0.017)	(0.472)	(0.477)	(0.492)
Sunshine		–0.461**	–0.502	–0.072		0.788	0.642	1.261
		(0.216)	(0.354)	(0.497)		(0.790)	(0.804)	(0.812)
Air quality×Sunshine		0.283***	0.313***	0.291**		–0.164	–0.157	–0.115
		(0.099)	(0.105)	(0.112)		(0.186)	(0.188)	(0.194)
Household per capita income	–0.023***	–0.023***	–0.023***	–0.023***	–0.024***	–0.023***	–0.023***	–0.023***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Relative income	–0.037***	–0.037***	–0.037***	–0.037***	–0.037***	–0.037***	–0.037***	–0.037***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Age (÷10)	0.059***	0.059***	0.059***	0.058***	0.060***	0.060***	0.061***	0.060***
	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
Age (÷10) squared	–0.005***	–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)	(0.002)
Male	–0.079***	–0.079***	–0.079***	–0.079***	–0.078***	–0.078***	–0.078***	–0.078***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Married	–0.115***	–0.115***	–0.115***	–0.114***	–0.114***	–0.114***	–0.115***	–0.114***
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Divorced	0.042	0.043	0.043	0.043	0.041	0.041	0.042	0.042
	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)
Education	–0.009***	–0.009***	–0.009***	–0.009***	–0.010***	–0.010***	–0.010***	–0.009***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Unemployed	0.101***	0.106***	0.106***	0.105***	0.100***	0.102***	0.102***	0.103***
	(0.033)	(0.032)	(0.032)	(0.033)	(0.034)	(0.033)	(0.033)	(0.033)
State employee	–0.006	–0.006	–0.006	–0.005	–0.006	–0.006	–0.006	–0.005
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Party	–0.039***	–0.039***	–0.039***	–0.039***	–0.037***	–0.037***	–0.037***	–0.037***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Chronic disease	0.115***	0.114***	0.114***	0.115***	0.113***	0.113***	0.113***	0.114***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
County fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	No	No	Yes	Yes	No	No	Yes	Yes
Month, day-of-week fixed effects	No	No	No	Yes	No	No	No	Yes
Observations	13,433	13,433	13,433	13,433	13,483	13,483	13,483	13,483
Adjusted *R*-squared	0.147	0.148	0.148	0.149	0.147	0.147	0.147	0.148

Source: China Family Panel Studies 2012.

Note: This table presents the full results in Table 5. The weather controls include mean temperature and its square, temperature difference (daily maximum-minimum), total precipitation, maximum sustained wind speed, and a dummy for bad weather. Robust standard errors, clustered at the county level, are presented in parentheses. API = air pollution index.

**5% significance level. ***1% significance level.

Table A5: Effect of air quality (visibility versus API) on severe depression, cross-sectional

Dependent variable	Visibility				API			
Severe depression	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Air quality	0.005	–0.344**	–0.376**	–0.330**	–0.019	0.249	0.325	0.255
	(0.012)	(0.143)	(0.145)	(0.145)	(0.012)	(0.258)	(0.284)	(0.293)
Sunshine		–0.145	–0.210	–0.025		0.540	0.523	0.771
		(0.133)	(0.213)	(0.321)		(0.434)	(0.461)	(0.472)
Air quality×Sunshine		0.137**	0.149**	0.131**		–0.099	–0.130	–0.101
		(0.059)	(0.060)	(0.060)		(0.102)	(0.113)	(0.117)
Household per capita income	–0.015***	–0.015***	–0.015***	–0.015***	–0.016***	–0.015***	–0.015***	–0.015***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Relative income	–0.027***	–0.027***	–0.027***	–0.027***	–0.027***	–0.027***	–0.027***	–0.027***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Age (÷10)	0.056***	0.055***	0.055***	0.054***	0.056***	0.056***	0.056***	0.055***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Age (÷10) squared	–0.004***	–0.004***	–0.004***	–0.004***	–0.004***	–0.004***	–0.004***	–0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Male	–0.055***	–0.055***	–0.055***	–0.055***	–0.055***	–0.054***	–0.054***	–0.054***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Married	–0.093***	–0.094***	–0.094***	–0.093***	–0.093***	–0.093***	–0.093***	–0.092***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Divorced	–0.008	–0.007	–0.007	–0.007	–0.007	–0.007	–0.007	–0.007
	(0.025)	(0.024)	(0.024)	(0.024)	(0.025)	(0.024)	(0.024)	(0.024)
Education	–0.006***	–0.006***	–0.006***	–0.006***	–0.006***	–0.006***	–0.006***	–0.006***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Unemployed	–0.002	0.001	0.001	0.001	–0.003	–0.001	–0.001	0.000
	(0.023)	(0.023)	(0.023)	(0.024)	(0.023)	(0.023)	(0.023)	(0.024)
State employee	0.011	0.012	0.012	0.012	0.011	0.012	0.012	0.012
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Party	–0.031***	–0.031***	–0.031***	–0.031***	–0.030***	–0.029***	–0.029***	–0.029***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Chronic disease	0.102***	0.101***	0.101***	0.101***	0.100***	0.100***	0.100***	0.100***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
County fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	No	No	Yes	Yes	No	No	Yes	Yes
Month, day-of-week fixed effects	No	No	No	Yes	No	No	No	Yes
Observations	13,433	13,433	13,433	13,433	13,483	13,483	13,483	13,483
Adjusted *R*-squared	0.113	0.115	0.115	0.115	0.113	0.114	0.114	0.115

Source: China Family Panel Studies 2012.

Note: This table presents the full results in Table 6. The weather controls include mean temperature and its square, temperature difference (daily maximum-minimum), total precipitation, maximum sustained wind speed, and a dummy for bad weather. Robust standard errors, clustered at the county level, are presented in parentheses. API = air pollution index.

**5% significance level. ***1% significance level.

Table A6: Placebo test—Air visibility forwarded by a week

Dependent variable	Life satisfaction (1)	Hedonic happiness (2)	Mental well-being (3)	Depressive symptoms (4)	Severe depression (5)
Air quality_F7	0.349	2.000**	–0.246	–0.456	–0.049
	(0.820)	(1.008)	(0.291)	(0.526)	(0.291)
Sunshine_F7	0.503	0.829	0.277	0.083	0.170
	(1.150)	(1.199)	(0.383)	(0.655)	(0.394)
Air quality_F7×Sunshine_F7	–0.116	–0.766*	0.098	0.181	0.020
	(0.318)	(0.400)	(0.114)	(0.207)	(0.116)
Household per capita income	0.023*	0.055***	0.001	–0.024***	–0.016***
	(0.012)	(0.010)	(0.004)	(0.005)	(0.004)
Relative income	0.202***	0.065***	–0.017***	–0.037***	–0.027***
	(0.012)	(0.009)	(0.003)	(0.005)	(0.004)
Individual fixed effect	Yes	No	Yes	No	No
County fixed effect	No	Yes	No	Yes	Yes
Demographic controls	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes
Year, month, day-of-week fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	27,466	13,719	27,123	13,466	13,466
Adjusted *R*-squared	0.053#	0.139	0.026#	0.148	0.115

Source: China Family Panel Studies 2010 and 2012.

Note: The weather controls include mean temperature and its square, temperature difference (daily maximum-minimum), total precipitation, maximum sustained wind speed, and a dummy for bad weather, and they are all forward seven days. Demographic controls include gender, age and its square term, years of education, marital status ("married" dummy and "divorced" dummy, "never married" is the reference category), unemployment status, state employee status, party membership and chronic disease status. Robust standard errors, clustered at the county level, are presented in parentheses. # indicates adjusted (within) *R*-squared. *10% significance level. **5% significance level. ***1% significance level.

Table A7: Heterogeneity test of air quality effect, by gender and age

A. Hedonic happiness						
Dependent variable	Male			Female		
Hedonic happiness	Young (16–39)	Middle (40–59)	Old (60 and older)	Young (16–39)	Middle (40–59)	Old (60 and older)
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable mean	*2.937*	*2.904*	*2.900*	*2.900*	*2.763*	*2.751*
Visibility	0.740	1.638	0.405	1.815**	2.007**	3.532**
	(1.209)	(1.229)	(1.200)	(0.836)	(0.904)	(1.719)
Sunshine	0.609	–0.386	–1.434	–0.685	2.088	0.662
	(1.883)	(2.162)	(1.996)	(1.713)	(1.540)	(3.120)
Visibility×Sunshine	–0.239	–0.627	–0.154	–0.666*	–0.763**	–1.345*
	(0.488)	(0.492)	(0.474)	(0.348)	(0.363)	(0.687)
Observations	1,667	3,154	1,878	1,840	3,445	1,698
Adj. *R*-squared	0.159	0.127	0.140	0.146	0.136	0.146

B. Mental well-being						
Dependent variable	Male			Female		
Percentile of the CES-D score	Young (16–39)	Middle (40–59)	Old (60 and older)	Young (16–39)	Middle (40–59)	Old (60 and older)
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable mean	*0.447*	*0.449*	*0.449*	*0.490*	*0.515*	*0.526*
Visibility	–0.178	–0.606*	–0.717	–0.347	–0.563**	–1.053***
	(0.389)	(0.309)	(0.451)	(0.555)	(0.261)	(0.376)
Sunshine	0.760	0.083	–0.803	0.635	0.215	–1.158*
	(0.498)	(0.456)	(0.569)	(0.583)	(0.352)	(0.610)
Visibility×Sunshine	0.062	0.244**	0.281	0.130	0.221**	0.427***
	(0.153)	(0.122)	(0.176)	(0.220)	(0.103)	(0.147)
Observations	3,592	6,278	3,434	3,958	6,789	3,019
Adj. (within) *R*-squared	0.069	0.044	0.019	0.053	0.032	0.045

Source: Panel A is from the China Family Panel Studies (CFPS) 2012, and panel B is from CFPS 2010 and CFPS 2012.

Note: Lower percentile of the CES-D score indicates better mental well-being. In panel A, other covariates and fixed effects are the same as those in column (4) of Table 3. In panel B, other covariates and fixed effects are the same as those in column (4) of Table 4. Robust standard errors, clustered at the county level, are presented in parentheses. Adj. = Adjusted; CES-D = Center for Epidemiologic Studies Depression scale.

*10% significance level. **5% significance level. ***1% significance level.

Table A8: Summary statistics of subjective well-being in China, 1990–2012

	World Values Survey				CCTV Postcard Survey		Horizon Research	
	Life Satisfaction (1–10)		Happiness (1–4)		Happiness (1–5)		Urban Life Satisfaction (1–5)	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
1990	7.292	2.101	2.946	0.813				
1995	6.833	2.418	3.052	0.659				
1997							3.69	
1998							3.48	
1999							3.44	
2000							3.27	1.05
2001	6.530	2.468	2.868	0.634			3.28	1.13
2002							3.33	1.12
2003							3.26	1.03
2004							3.38	1.01
2005							3.28	0.84
2006							3.52	0.86
2007	6.760	2.395	2.936	0.749	3.623	0.921	3.35	0.84
2008					3.623	0.973	3.51	0.74
2009					3.560	0.964	3.47	0.72
2010					3.477	1.008	3.41	0.79
2011					3.396	0.983	3.53	0.76
2012	6.858	1.985	3.006	0.585	3.477	1.001	3.57	0.69

Source: World Values Survey, CCTV Postcard Survey, and Horizon Research Constancy Group.

Note: World Values Survey (1990, 1995, 2001, 2007, 2012)—Life satisfaction: All things considered, how satisfied are you with your life as a whole these days? ([*dissatisfied*] 1 2 3 4 5 6 7 8 9 10 [*satisfied*]). Happiness: Taking all things together, would you say you are: *very happy, quite happy, not very happy,* or *not at all happy?* (coded 4, 3, 2, or 1). CCTV Postcard Survey (2007–2013) (in Chinese)—Happiness: How do you feel about your current life? (*very happy, fairly happy, just so-so, not happy,* or *very unhappy;* coded 5, 4, 3, 2, or 1). Horizon (1997–2013) (in Chinese)—Life satisfaction: In general, are you satisfied with your current life? (*very satisfied, fairly satisfied, average, fairly dissatisfied,* or *very dissatisfied;* coded 5, 4, 3, 2, or 1).

Online Appendix B: Center for Epidemiologic Studies Depression scale (CES-D) in China Family Panel Studies (CFPS)

20-item CES-D in CFPS 2012

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 week.

1. *Rarely or None of the Time (Less than 1 Day)*
2. *Some or a Little of the Time (1–2 Days)*
3. *Occasionally or a Moderate Amount of Time (3–4 Days)*
4. *Most or All of the Time (5–7 Days)*

During the past week:

1. *I was bothered by things that usually don't bother me.*
2. *I did not feel like eating; my appetite was poor.*
3. *I felt that I could not shake off the blues even with help from my family or friends.*
4. *I felt that I was just as good as other people.*
5. *I had trouble keeping my mind on what I was doing.*
6. *I felt depressed.*
7. *I felt that everything I did was an effort.*
8. *I felt hopeful about the future.*
9. *I thought my life had been a failure.*
10. *I felt fearful.*
11. *My sleep was restless.*
12. *I was happy.*
13. *I talked less than usual.*
14. *I felt lonely.*
15. *People were unfriendly.*
16. *I enjoyed life.*
17. *I had crying spells.*
18. *I felt sad.*
19. *I felt that people dislike me.*
20. *I could not get "going."*

Six-item CES-D in CFPS 2010

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.

1. *Never*
2. *Sometimes*
3. *Half the Time*
4. *Often*
5. *Almost Every Day*

During the past month:

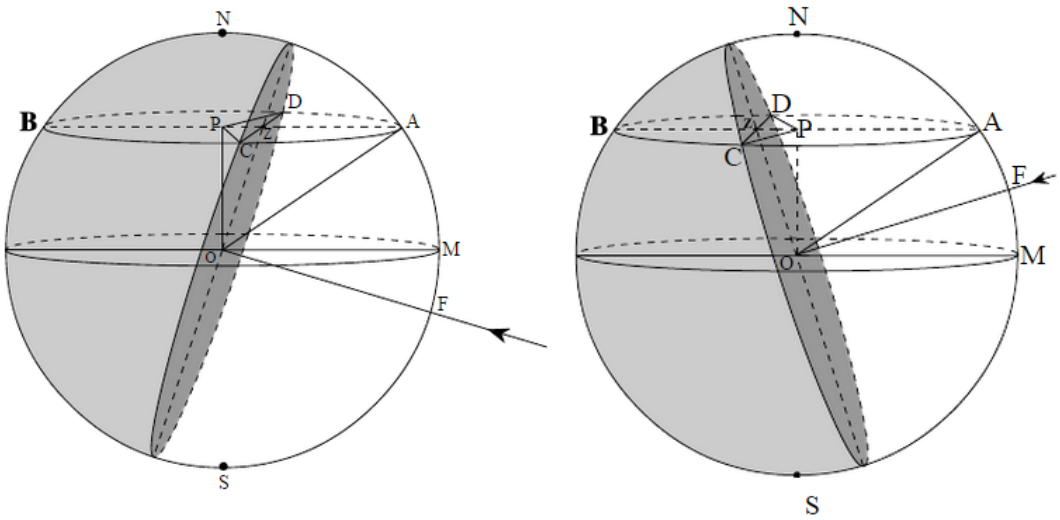
1. *I felt depressed and nothing can cheer me up.*
2. *I felt nervous.*
3. *I felt restless and hard to calm down.*
4. *I felt hopeless about the future.*
5. *I felt that everything I did was an effort.*
6. *My life was meaningless.*

Online Appendix C: Sunshine duration calculation formula

The formula we use to calculate sunshine duration (hours) is as follows:

$$sunshinehours = 24 \times \frac{\arccos(\tan\alpha \tan\beta)}{180^{\circ}} \quad \text{(A.1)}$$

Where α is the latitude of county *j*, and β is the latitude of direct sunshine point at date *t*. Noting that β is assumed to be positive if the location of the county and the direct sunshine point are on different hemispheres (left figure), while β is negative if they are on the same hemisphere (right figure).



$\angle AOM = \alpha$, $\angle FOM = \beta$ $\angle AOM = \alpha$, $\angle FOM = -\beta$

Source: www.126doc.com/p-38513483.html.