AIR POLLUTION AND HAPPINESS: EVIDENCE FROM THE COLDEST CAPITAL IN THE WORLD

by

CHIMEDREGZEN SANDUIJAV

(Under the Direction of SUSANA FERREIRA)

ABSTRACT

The transition from a centrally planned socialist economy to free markets brought unprecedented economic growth to Mongolia, but also severe environmental problems associated with rapid urban development. Its capital city Ulaanbaatar (UB) has experienced extreme air pollution during the Winter months for almost two decades. While the impacts of local air pollution on cardiovascular and respiratory health are well documented, this is the first study to evaluate the relationship between individuals' subjective well-being and particulate matter concentrations. By combining newly available survey data on subjective well-being in UB and particulate matter readings from monitoring stations and weather data, I found significant relationship between air pollution and life satisfaction in UB. The estimated coefficients imply a sizeable residents' willingness-to-pay for better air quality, in the order of $191 annually for a 10 $\mu g/m^3$ (or a 5.6%) reduction in daily average concentrations.

INDEX WORDS: air pollution, particulate matter, subjective well-being, life satisfaction, happiness, willingness to pay

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CHIMEDREGZEN SANDUIJAV

Major Professor:	Susana Ferreira
Committee:	Mateusz Filipski
	Yukiko Hashida

Electronic Version Approved:

Ron Walcott
Interim Dean of the Graduate School
The University of Georgia
May 2020

DEDICATION

I would like to dedicate my thesis to my family who gave me their endless support and love through the journey in the United States of America.

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CHAPTER 1

INTRODUCTION

Mongolia is a land-locked central Asian country sandwiched between two giants, Russia and China. It has over 3 million people living in a vast mass of land and is one of the few remaining countries in the world where there is a combined sedentary and nomadic lifestyle. After 70 years of communism, the country transitioned from a centrally planned socialist economy to a free market economy at the beginning of 1990s. Between 1990 and 2018, its GDP increased over five times from 2.561 to 13.067 billion USD (World Bank, 2020). This dramatic economic growth has been accompanied by increases in income inequality (Geleg and Dalkhjav, 2016) and migration to the capital, Ulaanbaatar (Figure 1). As a matter of fact, the National Statistics Office (NSO) of Mongolia, estimates that the number of residents in Ulaanbaatar went up from 586,228 to 1,491,375 over the same period (NSO, 2019), which increased the proportion of population in Ulaanbaatar (UB from short) relative to the whole nation roughly from a quarter to a half. Even though Mongolia has the lowest population density in the world with only 1.9 people per square kilometer (Junior, 2018), 317 people per square kilometer lived in the capital in 2018. [1]

[1] I calculated this number dividing the total population in UB in 2018 by its area (1491375 people/4,704.4 sq. km)

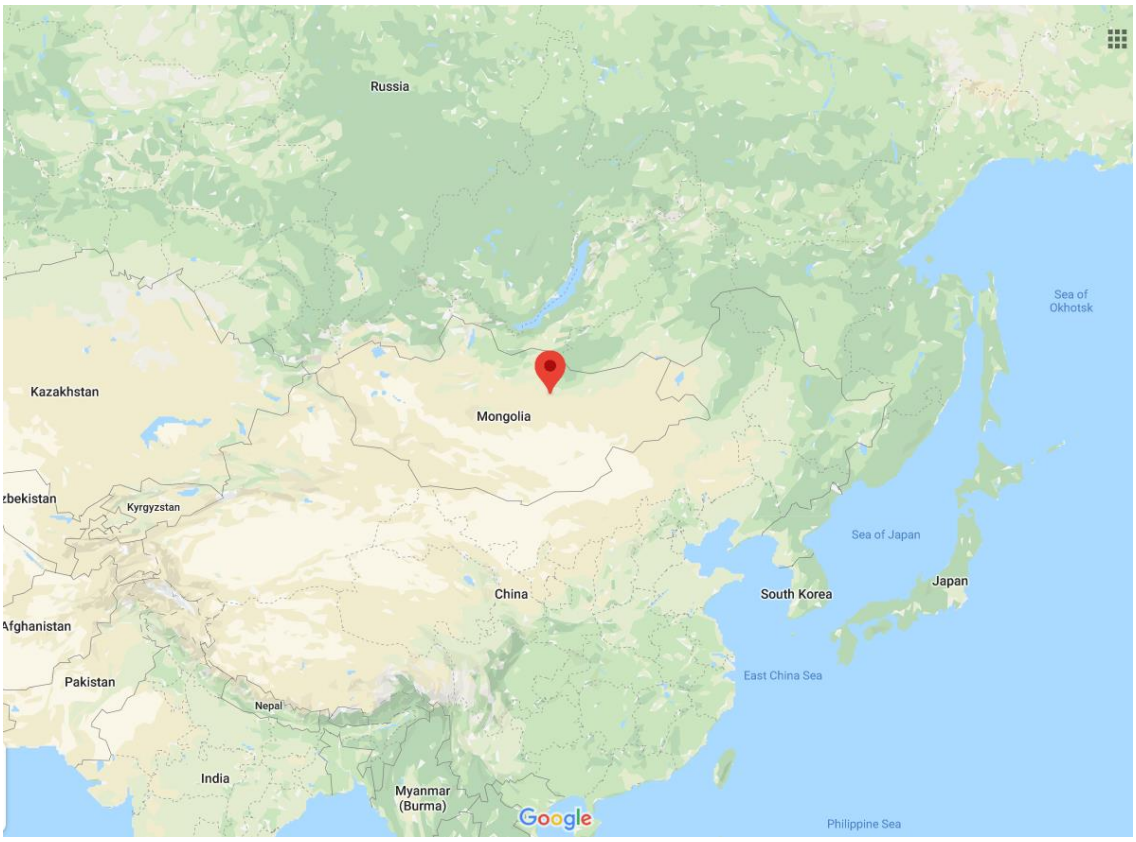

Figure 1. Map of Mongolia

Note: Red pin indicates the location of Ulaanbaatar in Mongolia / Source: Google Maps

The rapid growth of UB, coupled with an uneven pattern of economic development, have contributed to severe poverty and air pollution problems. The percentage of poor living in urban areas climbed up from 55.2 to 63.5 percent in the period 2010-2018 and 40 percent of all poor people were living in UB in 2018 while the poverty rate declined by 4.1 percent in rural areas between 2016 and 2018 (World Bank, 2019). Because many of the poor in UB cannot afford to buy apartments, they are forced to live in the emerging "Ger" district (Figure 2), a low-income, suburban area, which comprised 211,300 households or 53.9 percent of the UB total in 2018 (NSO, 2019).

Figure 2. Ger District
Source: Kristin Kelly Colombano/The Asia foundation

The Ger district consists mostly of tiny houses and ger (a Mongolian traditional yurt-like round housing) not connected to the central heating system. Thus, people living in the area burn raw coal[2] in traditional iron stoves for heating during the cold season and often for cooking. Indeed, households and low-pressure boilers burning raw coal in the Ger district account for 80 percent of total air pollution in UB during the winter, with emissions from coal-fired power plants and motor vehicle exhaust playing a secondary role (Surenjav et al., 2018).

The cold season in Mongolia can be very long, extending from October to March/April (Nandintsetseg, et al. 2018), and very cold. UB is the coldest capital city in the world with a yearly mean temperature of −3.7 °C (Hauck, 2008) equivalent to 25°F. UB's mean temperature in January, the coldest month of the year, was -21.5°C (-6.7°F) during the period 2000 – 2018 (NSO,

[2] In a coal-rich country, raw coal is their cheapest option. It also burns longer than other fuels.

2019) and night temperatures can fall to -40°C. In addition to the cold, its geographic location — at the bottom of a valley— creates a thermal inversion effect. A layer of cool air gets trapped between mountains in the north and the south below a layer of warm air, keeping pollution near the ground (Davy et al., 2011).

The annual mean concentration of fine particulate matter (PM2.5) during 2011-2018 was roughly 6 to 13 times higher than the WHO Air Quality Guidelines (Figure 3). Similarly, the annual mean concentration of coarse particulate matter (PM10) during 2009-2018 was about 6 to 14 times higher than WHO Air Quality Standard (Figure 3). This has significant implications for health by increasing mortality and morbidity rates from cardiovascular and respiratory diseases. For instance, the World Bank (2011) estimates that during the period June 2008 – May 2009 a 10 μg/m3 increase in PM10 increased daily cardiovascular mortality by 0.25 percent. Allen et al. (2013) estimated that 9.7 percent of the total deaths in UB in 2009 (623 deaths) were attributable to air pollution. Similarly, Guttikunda et al. (2013) concluded that outdoor particle pollution caused 1,000-1,500 premature deaths per year by aggravating respiratory and cardiovascular conditions for a total city population of 1.2 million in 2010.

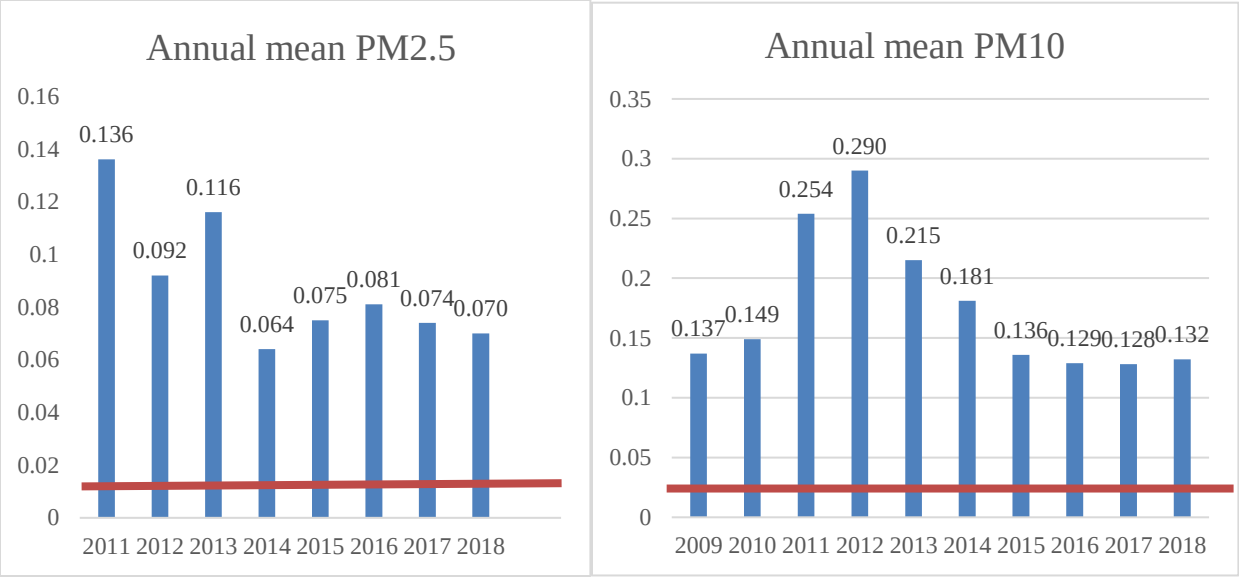

Figure 3. Annual Mean Concentration [mg/m3] of PM2.5 (left) and) PM10 (right)
Blue bars: Annual mean concentration | Orange line: WHO air quality guideline (0.01 mg/m3 for PM2.5 and 0.02 mg/m3 for PM10)
Source: Ambient air pollution and health of Ulaanbaatar, NSO, 2019

Previous studies, however, have not evaluated the potential effect of air pollution on the mental health and subjective well-being (SWB) of the residents of UB. This effect is likely to be substantial. A rapidly growing literature has documented negative effects of environmental degradation in general, and air pollution in particular, on self-reported indicators of life satisfaction and happiness in Ireland (Brereton et al. 2008, Moro et al. 2008), the UK (Mackerron and Mourato 2009), the United States (Levinson 2012), Australia (Ambrey et al. 2014), China (Li et al. 2014; Zhang et al. 2017), and Europe (Welsch 2006 & 2007; Ferrer-i-Carbonell and Gowdy 2007; Luechinger 2010; Ferreira et al. 2013; Goetzke and Rave 2015; Orru 2016) This literature relies on surveys where respondents are asked to evaluate their overall satisfaction with life, happiness or positive and negative affects. Happiness functions are built where these indicators of self-reported SWB are related to individual socioeconomic characteristics and environmental conditions, notably air pollution. Evaluating this relationship is rather important in Mongolia. Mongolia is best known as the “land of the eternal blue sky” for its abundance of sunny days and

wide landscapes that allow one to see blue sky all around. In UB, however, every winter the legendary blue sky turns hazy as the air thickens with highly noticeable particle pollution that impairs visibility (Figure 4). Anecdotally, some parents in UB did not let their children go to school for weeks in order to protect them from toxic air outside during Winter of 2019 (Timsit, 2019). Also, data collected by Government of Mongolia (GOM) reported that particles level on January 30th, 2018 reached 3,320 µg/m^3 at "Baruun 4 zam" monitoring station which is 133 times the WHO guidelines (National Center for Public Health and UNICEF, 2018). This concern about the effects of air pollution on the health of loved ones is in addition to the effects on one's own cardiovascular and respiratory health.

Figure 4. City center of Ulaanbaatar during mid-December 2019
/Source: Purevdorj Tseveendorj/

I used survey data from the Independent Research Institute of Mongolia (IRIM), and data on air pollution (PM 2.5 and PM10) and weather, to estimate a life satisfaction (LS) function. I

matched the respondents' answers with the PM readings and weather data of the same day and find air pollution effect on people's LS.

In addition to estimating the direct contribution of PM concentrations to the LS of the average UB resident, we monetize the marginal contribution of PM concentrations to well-being. The LS approach has been used to infer the monetary value of non-marketed goods. One can use self-reported SWB as a proxy for the individual's utility and compute directly the marginal rate of substitution between income and air pollution, its elasticity (with respect to income) and other welfare measures (equivalent and compensating surpluses) (Frey et al. 2010; Welsch and Ferreira 2014; Atkinson et al. 2018). In this paper we use the LS approach to estimate the marginal Willingness to Pay (WTP) to reduce PM10 concentrations. These estimates can inform environmental policy, such as the recently implemented coal ban,[3] in a benefit-cost analysis framework.

The rest of the thesis is organized as follows. Section 2 introduces the literature analyzing the relationship between air pollution and SWB. Then, section 3 describes the data used in the research. Section 4 presents the methodology and section 5 the results. Finally, section 6 concludes with a summary and future research directions.

[3] In accordance with the 2017 Mongolia national program on reduction of air and environmental pollution, Government of Mongolia (GOM) implemented a ban on burning unprocessed raw coal in households, companies and enterprises, except enterprises with special licenses for energy and electricity generation, to be effective on May 15th, 2019. At the same time, by September 2019 GOM prepared 600,000 tonnes of cleaner processed fuel to be distributed through selling stations with affordable discounted prices to Ger district households. As a result, PM2.5 and PM10 concentrations in UB reportedly have been reduced compared to previous years according to National Agency of Meteorology and Environment Monitoring (NAMEM).

CHAPTER 2

LITERATURE REVIEW

The use of happiness data in economics is relatively new. The earliest well-known contribution is Easterlin (1974) who found a positive correlation between income and self-reported happiness at a given time within a country, but that happiness does not increase as income grows over time. This puzzling result - the "Easterlin Paradox" - was the start of a fruitful area of research and sparked the "economics of happiness" literature. Some studies have challenged the paradox by showing that economic growth is associated with happiness (Deaton, 2008; Stevenson and Wolfers, 2008) and that the effect of higher income is muted by marriage and divorce (Angeles, 2011), and intensity of social inequality (Li and Shi, 2019). In addition, many studies have used happiness data to understand socioeconomic and macroeconomic determinants of happiness: unemployment (Clark and Oswald, 1994), institutions (Frey and Slutzer, 2000), tradeoffs between unemployment and inflation (Di Tella et al., 2001), peer social relationship (Burton and Phipps, 2008), and terrorism (Frey et al., 2009). Environmental conditions have also been shown to influence individuals' LS and happiness; among them airport noise (Van Praag and Baarsma, 2005), climate (Rehdanz and Maddison, 2005), environmental degradation (Ferrer-i-Carbonell and Gowdy 2007), environmental amenities (Moro et al., 2008), and natural hazards (Luechinger and Raschky, 2009).

In recent years economists have investigated the potential of the LS approach as a tool for non-market valuation. The estimation of a LS function allows the calculation of the marginal rate

of substitution (MRS) between income and a given environmental good that keeps LS constant, and subsequently determine the value of that specific non-market good (Welsch 2006, 2007; Ferreira and Moro 2010; Atkinson et al. 2018). By asking people how satisfied they are with life, the LS approach avoids some difficulties revealed preference (RP) and stated preference (SP) approaches. For instance, both RP and SP assume that agents are completely aware of environmental conditions. In addition, RP methods assume that agents are rational and there are no transaction costs, while SP methods (e.g. contingent valuation) may suffer from strategic behavior and other biases since it is a hypothetical scenario (Welsch, 2006). The LS approach does not rely on people's rationality or awareness of cause-effect relationships. Van Praag and Barsma (2005) and Ferreira and Moro (2010) showed that the LS approach can complement hedonic pricing when the market is out of equilibrium. Moreover, strategic behavior responses should not matter since individuals are not asked about environmental condition or change but simply about satisfaction with their own life. However, LS approach also has disadvantages. Firstly, it is treated as a proxy for the individual's indirect utility function and it makes interpersonal comparisons by using respondents' quantitative answers. Secondly, there is a concern over endogeneity of income variable (Frey and Slutzer, 2002). As wealthier people tend to be happier, happier individuals also have more tendencies to be richer simultaneously. Despite these shortcomings, the LS approach has been proven to a useful additional method in the non-market valuation toolkit (Atkinson et al. 2018).

CHAPTER 3

DATA

In order to estimate the relationship between air pollution and LS in UB, I used 3 datasets: (1) survey data from the Independent Research Institute of Mongolia (IRIM) which contains SWB and sociodemographic information; (2) air pollution data from OpenAQ platform, a publicly open dataset of air pollutants; (3) meteorological data from the Mongolian National Agency of Meteorology and Environmental Monitoring (NAMEM). The full list of variables with their description is given in table A1 in the appendix.

3.1. Survey Data

IRIM, an NGO established in 2008, is one of Mongolia's leading national organizations specializing in research, monitoring and evaluation, training, advocacy and consulting projects, and it promotes independent third-party researches as institutional practice.[4] During 2016-2018 they carried out the first ever Mongolian-wide "Social Well-being" survey (IRIM 2018). A total of 809 UB residents were interviewed face to face at their domiciles during June 10th – 13th, 2016 (493) and February 2nd to 4th, 2017 (316).[5] Surveyed UB residents come from six main districts: Bayangol, Bayanzurkh, Chingeltei, Khan-Uul, Songinokhairkhan and Sukhbaatar.[6] The survey relies on OECD's framework on measuring SWB. Accordingly, surveyed individuals were asked

[4] Since 2008, they carried out over 160 projects and they are member of Asian Network of Social Accountability (ANSA), and the International Sociological Association (ISA). For more info, visit their website https://www.irim.mn/about-us

[5] IRIM has not made their survey data publicly available yet, however, they were generous enough to provide me their SWB data upon email and phone call request.

[6] UB consists of 9 districts in total, however, 3 other districts (Nalaikh, Baganuur and Bagakhangai) are not in the main UB and they locate in distant places.

a LS question: “Overall, how satisfied are you with your life as a whole these days?” on a scale from 0 to 10, with 0 being “not satisfied at all” and 10 being “completely satisfied”. There were also questions about their satisfaction with their own health, local environment on a 10-point scale and how they felt on the previous day of the survey (“Did you experience any sadness yesterday?”, “Did you experience any happiness yesterday” on a 10-point scale with 0 being “not at all” and 10 being “all day”). The feelings on the previous day questions allow us to control for the emotional state of the individual. Overall, survey respondents reported to be relatively satisfied with their lives, with a mean of 7.21 out of 10 (Table 1).

The questionnaire asked socioeconomic and demographic questions including annual household income, age, sex, education, marital status, employment status, religion, ethnicity, in which district in which the respondent lives, number of household members and number of years living in the current place. IRIM survey sorts annual household income into 8 categories: 1) Less than 3.6 million tugriks[7] 2) 3.6 - 6 million 3) 6 - 8.4 million 4) 8.4 – 10.8 million 5) 10.8 – 13.2 million 6) 13.2 – 19.2 million 7) 19.2 – 25.2 million 8) more than 25.2 million. I converted categorical income into continuous income variable by taking the midpoint of each category and for the open-ended category I extrapolated it from the next-to-last category's midpoint using the frequencies of both the next-to-last and the last categories in a formula based on the Pareto curve (Hout 2004). [8,9]

[7] Tugrik is a Mongolian national currency and 1USD is equivalent to 2767MNT as of March 2020 (Bank of Mongolia).

[8] The formula is $M_{top} = L_{top}\left(\frac{v}{v-1}\right)$ in which $v = \left(\frac{\log\left(f_{top-1}+f_{top}\right)-\log\left(f_{top}\right)}{\log\left(L_{top}\right)-\log\left(L_{top-1}\right)}\right)$, and L_{top} is the lower limit of the top category, L_{top-1} is the lower limit of the category before the top one, F_{top} is the frequency in the top category, and F_{top-1} is the frequency of the category before the top one.

[9] Beside of categorical income, the survey has continuous annual household income question of which 316 individuals reported and 493 are missing. Thus, I imputed continuous income for only those who did not reported.

Subsequently, household income was converted to individual income by applying the square root equivalence scale (as in OECD 2011).[10]

As shown in Table 1, survey respondents were aged between 13 and 88, almost half of them were male and their annual average income was 5,730,000 tugriks. Furthermore, three quarters of them had high school or bachelor's diploma, and little more than half were Buddhists. Almost nine in every ten people in the survey identified themselves as belonging to the Khalk ethnic group. Also, roughly half of them were married and employed full-time. As expected, the surveyed individuals were not very satisfied with the quality of their local environment with a mean of 5.3 out of 10 while being a little more satisfied with their own health condition with a mean of 6.5. The respondents were fairly distributed around the six districts and the proportions of districts and gender as well as average income are very similar to the official UB statistics. Thus, I assume that the sample is representative enough and we may interpret the regression results as applying to the average UB resident.

Table 1. Descriptive Statistics

Variable	Obs	Mean	Std.Dev.	Min	Max
Survey variables					
Life Satisfaction (LS)	799	7.21	2.289	0	10
Individual income	809	5730000	5230000	0	7.07e+07
Education level					
illiterate	809	.007	.086	0	1
literate_noschool	809	.009	.093	0	1
elementary	809	.022	.148	0	1
middle	809	.048	.214	0	1
secondary	809	.461	.499	0	1
vocational	809	.023	.152	0	1
special	809	.037	.189	0	1
diploma	809	.069	.254	0	1
bachelor	809	.29	.454	0	1
master	809	.027	.163	0	1
phd	809	.005	.07	0	1
age	809	35.734	15.606	13	88

[10] The square root scale divides household income by the square root of household size and implies that due to economies of scale a household of size four has similar needs to two adult individuals living separately.

age1325	809	.308	.462	0	1
age2545	809	.408	.492	0	1
age4560	809	.209	.407	0	1
age_over60	809	.075	.264	0	1
male	809	.494	.5	0	1
family	809	3.934	1.559	1	12
yearsliving	809	9.122	11.087	0	200
Districts					
sukhbaatar	809	.189	.392	0	1
songinokhairkhan	809	.222	.416	0	1
bayanzurkh	809	.192	.394	0	1
bayangol	809	.173	.379	0	1
khan_uul	809	.088	.283	0	1
chingeltei	809	.136	.343	0	1
Religion					
buddhist	809	.566	.496	0	1
atheist	809	.326	.469	0	1
christian	809	.028	.166	0	1
muslim	809	.005	.07	0	1
shamanist	809	.073	.26	0	1
Ethnicity					
khalkh	809	.892	.31	0	1
kazakh	809	.019	.135	0	1
durvud	809	.02	.139	0	1
buriat	809	.022	.148	0	1
bayad	809	.015	.121	0	1
dariganga	809	.006	.078	0	1
zakhchin	809	.004	.061	0	1
other_ethnic	809	.022	.148	0	1
Marital status					
married	808	.528	.499	0	1
living_separate	808	.009	.093	0	1
cohabitant	808	.025	.155	0	1
widowed	808	.047	.212	0	1
divorced	808	.04	.195	0	1
marriage_denied	808	.002	.05	0	1
Employment status					
full_time	809	.436	.496	0	1
part_time	809	.098	.297	0	1
unemployed	809	.041	.198	0	1
unemployed_nojobsearch	809	.067	.25	0	1
university_student	809	.193	.395	0	1
retired	809	.08	.272	0	1
lookafter_sick	809	0	0	0	0
lookafter_kid	809	.036	.186	0	1
student	809	.048	.214	0	1
herder	809	.001	.035	0	1
health	806	6.552	2.709	0	10
environment_satisfaction	795	5.323	2.64	0	10
happiness	803	6.842	2.567	0	10

sadness	802	3.408	3.041	0	10
Pollution variables					
pm10	809	176.573	154.269	39.006	512.609
pm25	809	126.583	139.218	20.816	517.54
Meteorological variables					
temperature	809	.954	15.405	-18.8	13.7
rainy	809	.514	.5	0	1

3.2 Pollution data

I collected PM2.5 and PM10 readings from 12 air pollution monitoring stations: 11 maintained by the Ministry of Environment and Tourism and 1 by US Embassy in UB. The data was compiled from the OpenAQ website, a publicly open and historical air quality data platform that aggregates government-measured and research-grade data. Although technically there are 12 monitoring stations scattered around the city, their data availability is not available consistently over all IRIM survey days in UB (Table 2).

Daily average air pollution was about 177 and 127 microgram/m^3 for PM10 and PM2.5 respectively and their maximum values were 513 and 518 microgram/m^3 which are roughly 11 and 21 times higher than WHO 24-hour guidelines respectively (Table 1). The daily average values were 63 and 31 microgram/m^3 for pm10 and pm2.5 respectively during summer survey days, and 353 and 276 microgram/m^3 in the winter survey dates which is a clear indication of seasonality.

Table 2. Availability of air pollution monitoring stations data on surveyed days

Number of stations that had available data for	6/10/2016	6/11/2016	6/12/2016	6/13/2016	2/2/2017	2/3/2017	2/4/2017
PM10	9	7	8	9	11	10	9
pm2.5	7	5	6	7	8	7	6

3.3. Meteorological data

As historical data were not publicly available, I personally contacted NAMEM and they provided the data upon request. It includes historical data of temperature, precipitation, wind speed and relative humidity during IRIM survey days. NAMEM dataset did not include any information on whether the day was sunny, cloudy or rainy. So, this part was compiled from Worldweatheronline, 2020. Nonetheless, seasonal rain patterns are correlated with air pollution, i.e. rain suppresses pollutants' concentrations. Summary of pollution and meteorological variables on each of the surveyed days is provided in Table A2 in the appendix.

CHAPTER 4

METHODOLOGY

4.1. Spatial interpolation of pollution data

As pollution data comes from 12 monitoring stations scattered in six main districts, the first task was to determine exposure of the surveyed individuals to air pollution. It would be ideal to know the actual exposure level of each individual, but I had to generalize individual's pollution exposure to district level as IRIM discloses address information at that level only. In order to mitigate measurement error, for the matching I used the population-weighted centroid of each district. For this, I used information on the population of each subdistrict (Figure 5) so that greater weight was assigned to a subdistrict with bigger population (figure 6) using Geographic Information Systems (GIS) software following Levinson (2012).

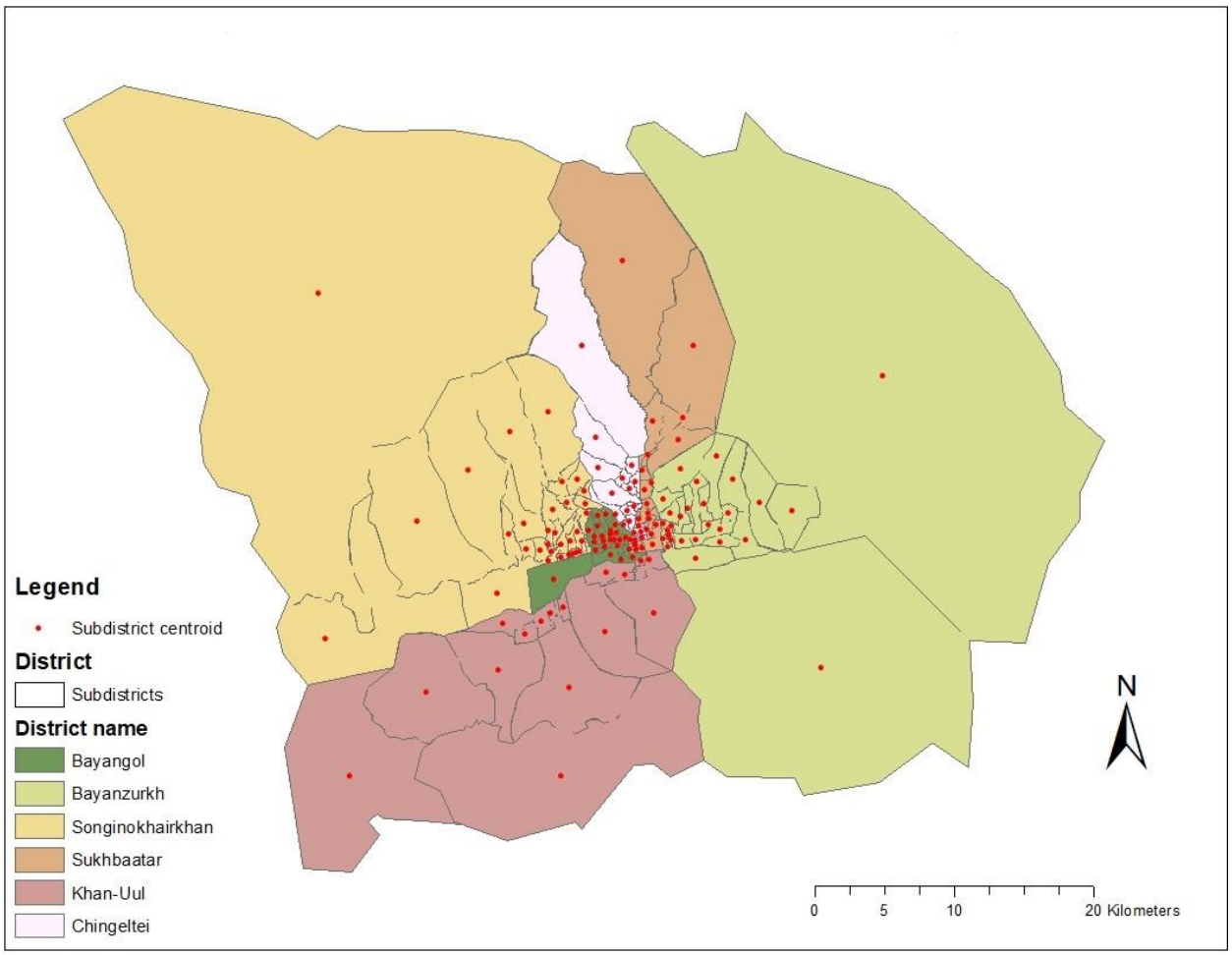

Figure 5. Subdistrict centroids of Ulaanbaatar

Note: GIS data of UB has been retrieved from Christopher M. Free's website11 which provides free GIS data of Mongolia and the map data was uploaded by Robert Ritz, a data scientist.

[11] https://marine.rutgers.edu/~cfree/gis-data/mongolia-gis-data/ (Christopher M. Free is a quantitative ecologist at Sustainable Fisheries Group of UC Santa Barbara.

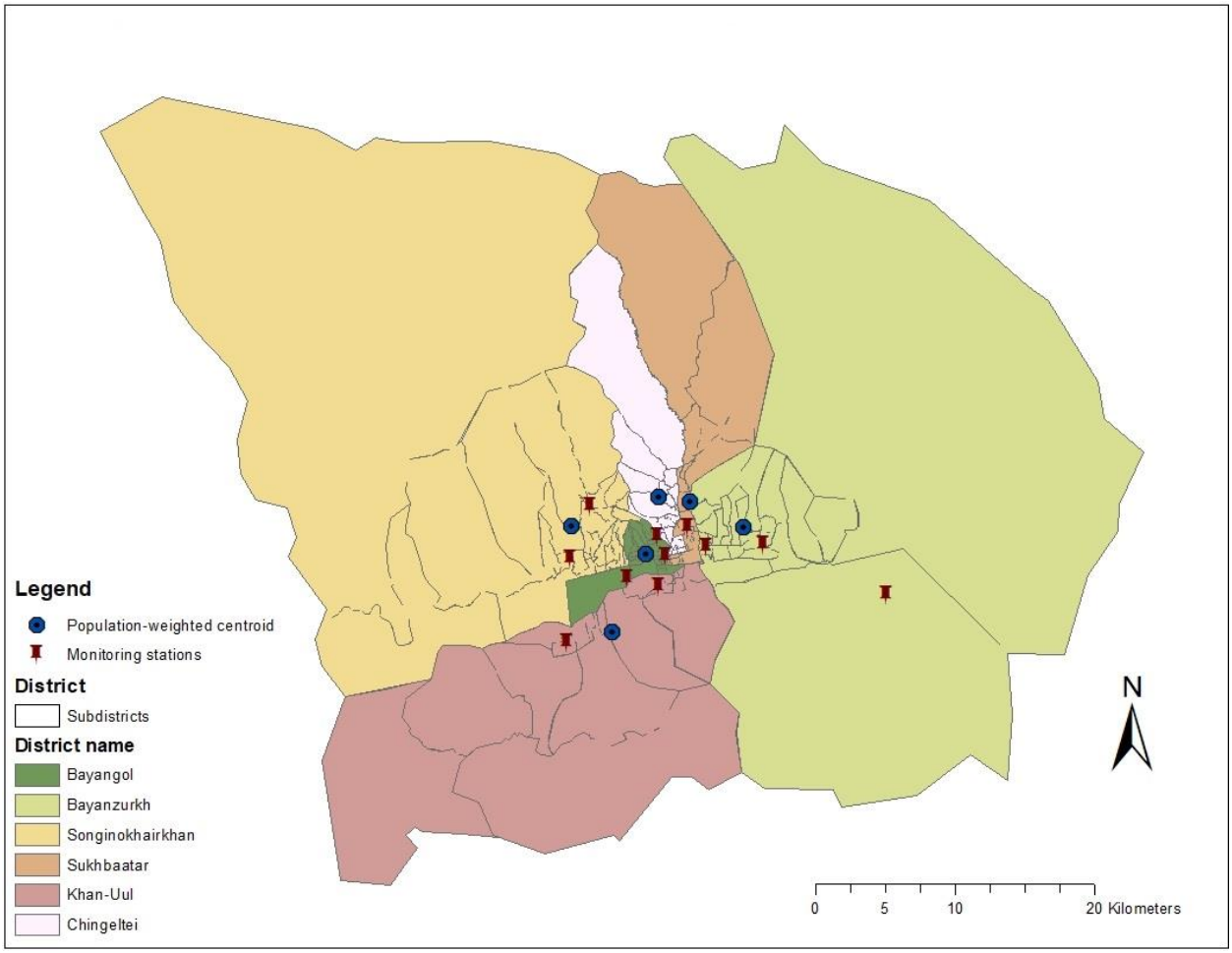

Figure 6. Pollution monitoring stations and Population-weighted centroids in each district

I used inverse-distance-weighted (IDW) interpolation with 100mx100m grid size with ArcGIS in order to calculate air pollution exposure of each district centroid taking all readings from surrounding monitoring stations which have available PM2.5 and PM10 concentrations data (Figure 7).

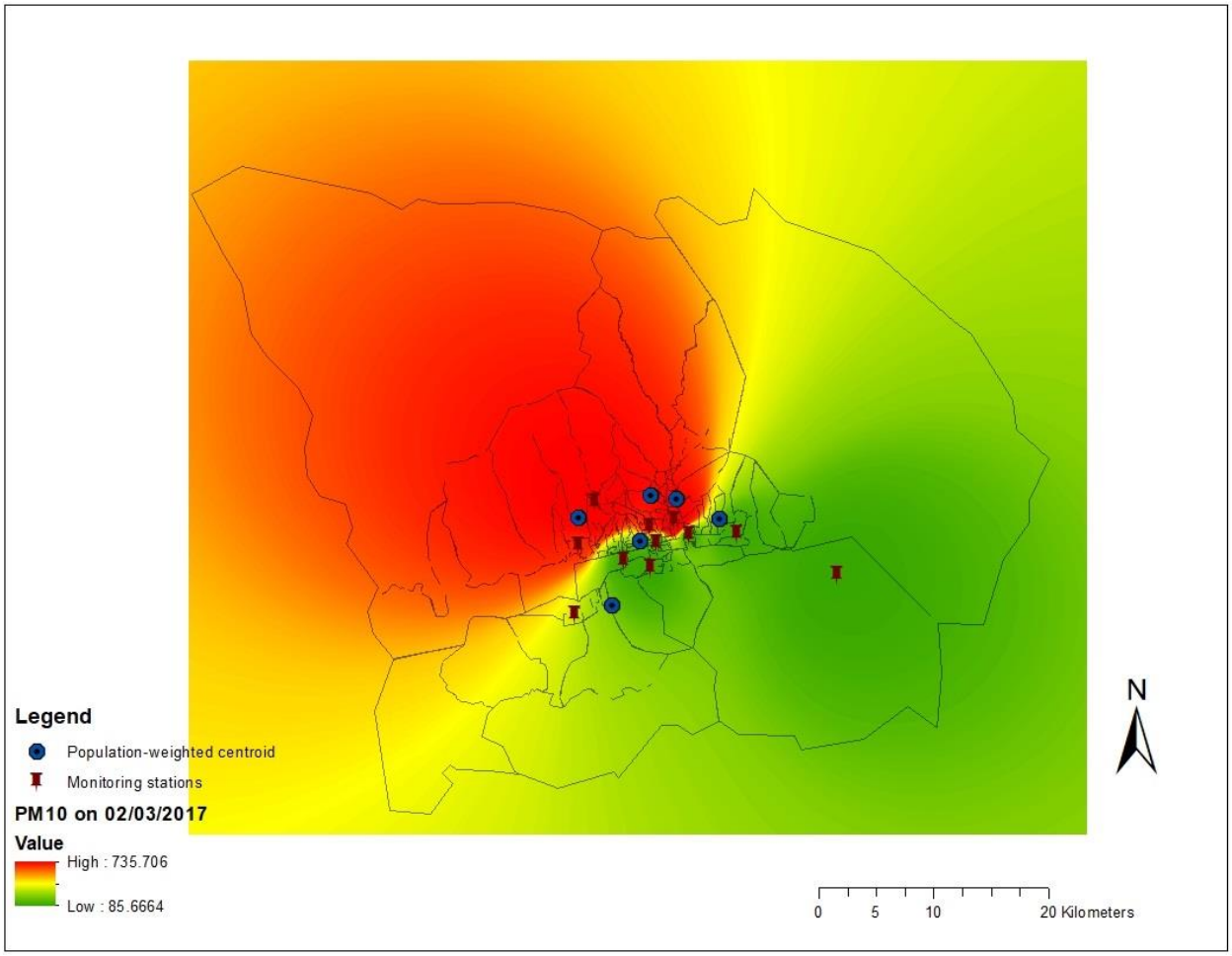

Figure 7. PM10 exposure on Feb 3rd, 2017 in Ulaanbaatar using IDW interpolation

Note: Northeastern part of UB is more polluted in this analysis which fits to the practical knowledge that Northeastern part is more polluted because it is densely populated by Ger district.

IDW assumes closer things have more impact than those further away and greater weight[12] is assigned to the points which are closest to the target location which in our case is population-weighted district centroids (for more information about IDW, see Shukla, 2020).

Ordinary Kriging (OK) is also regularly used in this kind of spatial interpolation analysis. Generally, OK is very similar to IDW as it also calculates weighted average of concentrations at monitoring stations to estimate location exposure; it uses weights derived from a function of distance referred to as a variogram which describes the degree of spatial dependence or

[12] In my calculation, I used weight of 2 which is the usual weight normally assigned in IDW.

autocorrelation (Rivera-Gonzalez et al. 2015). In their study, OK and IDW produced very similar results. Ferreira et al. (2013) preferred IDW because it is more suitable for rapid interpolation of in-situ air quality data. Also, Kim et al. (2009) and Wong et al. (2004) concluded that when monitoring density is low, as in our case with 6-11 stations depending on the day (refer to Table 2), different interpolation methods produce similar estimates. A limitation of both approaches is the absence of wind direction in the estimation. However, this would be less of an issue in UB case because of thermal inversion and pollution being trapped by the mountains close to the ground. Furthermore, I matched IRIM survey data with the estimated air pollution exposure as well as meteorological data including temperature and rainy/sunny days.

4.2. Estimation strategy

In order to estimate the air pollution and life satisfaction relationship, the following econometric model was employed:

$$LS_{ijt} = \delta + \alpha PM_{jt} + \gamma(\ln Y_{ijt}) + \beta_1' \mathbf{X_{ijt}} + \beta_2 T_{jt} + \beta_3 R_{jt} + \beta_4' \mathbf{A_i} + \varepsilon_{ijt,} \quad (1)$$

where LS_{ijt} is life satisfaction of the respondent *i*, at district *j* and at date *t*. The key explanatory variable PM_{it} is the air pollution (PM10 and/or PM2.5) concentrations at district *j* population-weighted centroid and at date *t*.

I included the log of income ($\ln Y_{ijt}$) which allows me to determine the relationship between a percentage change in income and individual LS and eventually the WTP for air quality improvement. $\mathbf{X}_{ijt}$ is a vector of socio-economic and demographic characteristics of an individual including age, gender, educational level, marital status, employment status, religion, ethnicity, and residing district. Also, T_{jt} and R_{jt} are in the model to control for temperature and general state of weather (rainy/cloudy=1, sunny=0). $\mathbf{A_i}$ indicates a vector of affect variable which captures *i* individual's mental state of the previous day since respondents' answers could be affected by their

mood. Finally, δ is the constant and ε_{ijt} is the error term. As the survey data is a repeated cross-section, not a panel, it did not allow me to control for unobserved individual characteristics.

Given the ordered nature of the dependent variable Equation 1 can be estimated with an Ordered Probit, which does not assume the dependent variable LS scale to be cardinal. Results from Ordered Probit and Ordinary Least Squares (OLS) models, however, have been demonstrated to be virtually identical (Ferrer-i-Carbonell and Fritjers 2004). Because of the ease of interpretation of OLS coefficients below we report the results from OLS regressions. The results from ordered probit regression are reported in Appendix Table A2.

To quantify the WTP for the reduction in air pollution we compute the marginal rate of substitution (MRS) between air pollution and income variables. That is, we calculate the tradeoff between PM and income that keeps LS constant:

$$(\partial \mathrm{LS}/\partial \mathrm{PM})/(\partial \mathrm{LS}/\partial \mathrm{Y}) = \mathrm{Y}\ (\frac{\alpha}{\gamma}), \qquad (2)$$

where Y is the individual income, α and γ are the coefficients of air pollution and log form of income respectively. MRS can be translated into the WTP to obtain increased air quality, i.e. the amount of income necessary to compensate for a one unit increase in air pollution. Basically, it is a tradeoff between income and pollution to leave the individual as satisfied as he or she was.

CHAPTER 5

RESULTS

Table 3 presents the OLS estimates of the LS equation (1) in six different specifications. First column shows baseline regression results and each next column presents additional controls one-by-one. Because PM2.5 and PM10 are highly correlated (ρ=0.93, Table 4.), I excluded PM2.5 from the regressions as PM10 data comes from more pollution monitoring stations. In regressions including both pollutants their Variance Inflation Factor (VIF) was larger than 10 which is a clear indication of multicollinearity (Appendix Table A4b). Not surprisingly, their coefficients were statistically insignificant when included together (Appendix Table A4a), but significant when included separately. I also ran regressions with only PM2.5 instead of PM10 and the results were very similar.

Table 3. LS regression - OLS estimates

VARIABLES	(1) Baseline Regression	(2) + Health & environment satisfaction	(3) + Health & env satisfaction & previous day mood	(4) + Health & env satisfaction & previous day mood +rain	(5) + Health & env satisfaction & previous day mood +rain +temp	(6) + Health & env satisfaction & previous day mood +temp
pm10	-0.00176***	-0.00192***	-0.00187***	-0.00171*	-0.000220	-0.000255
	(0.000219)	(0.000316)	(0.000456)	(0.000771)	(0.000906)	(0.000864)
log_income	0.303**	0.267**	0.223*	0.222*	0.221*	0.219*
	(0.0816)	(0.0944)	(0.0892)	(0.0921)	(0.0914)	(0.0886)
Age (reference: age13-25)						
age2545	-0.515***	-0.366**	-0.259**	-0.255*	-0.236*	-0.234**
	(0.0991)	(0.106)	(0.0910)	(0.102)	(0.0932)	(0.0904)
age4560	-0.755*	-0.525*	-0.319	-0.292	-0.369	-0.311
	(0.310)	(0.237)	(0.269)	(0.284)	(0.300)	(0.265)
age_over60	-0.924*	-0.671*	-0.659**	-0.655**	-0.593**	-0.599**
	(0.367)	(0.266)	(0.228)	(0.229)	(0.226)	(0.225)
male	0.0694	0.0655	0.0237	0.0226	0.0351	0.0308

	(0.101)	(0.148)	(0.158)	(0.161)	(0.167)	(0.159)
family	0.0443	0.0207	0.00698	0.00723	0.00570	0.00640
	(0.0824)	(0.0767)	(0.0596)	(0.0594)	(0.0588)	(0.0585)
yearsliving	0.000814	0.00170	0.00240	0.00234	0.00234	0.00225
	(0.00723)	(0.00821)	(0.00850)	(0.00858)	(0.00864)	(0.00845)
education	0.197***	0.143***	0.145***	0.145***	0.148***	0.148***
	(0.0347)	(0.0305)	(0.0288)	(0.0285)	(0.0280)	(0.0280)
Religion (reference: Buddhist)						
atheist	-0.277	-0.344**	-0.329**	-0.332**	-0.338**	-0.342**
	(0.162)	(0.132)	(0.106)	(0.112)	(0.112)	(0.105)
christian	-0.679	-0.614	-0.480	-0.482	-0.508	-0.507
	(0.450)	(0.459)	(0.379)	(0.383)	(0.377)	(0.378)
muslim	1.644	2.334*	2.146	2.145	2.125	2.127
	(0.914)	(1.135)	(1.155)	(1.159)	(1.152)	(1.158)
shamanist	-0.604	-0.496	-0.425	-0.427	-0.428	-0.430
	(0.562)	(0.563)	(0.530)	(0.534)	(0.534)	(0.533)
Ethnicity (reference: Khalkh)						
kazakh	-2.479**	-2.275**	-2.311**	-2.318**	-2.302**	-2.315**
	(0.792)	(0.750)	(0.743)	(0.744)	(0.719)	(0.736)
durvud	0.577	0.528*	0.528	0.529	0.514	0.519
	(0.349)	(0.259)	(0.349)	(0.348)	(0.337)	(0.333)
buriat	-0.150	-0.128	-0.0313	-0.0349	-0.0451	-0.0489
	(0.787)	(0.663)	(0.506)	(0.516)	(0.505)	(0.503)
bayad	-0.670	-0.736	-0.508	-0.517	-0.516	-0.530
	(0.478)	(0.703)	(0.738)	(0.735)	(0.740)	(0.749)
dariganga	0.855	0.756	0.519	0.528	0.551	0.561
	(0.863)	(0.891)	(0.855)	(0.859)	(0.901)	(0.900)
zakhchin	-1.709	-1.309	0.413	0.416	0.439	0.439
	(2.163)	(1.776)	(1.010)	(0.997)	(0.985)	(0.977)
other_ethnic	0.884	0.393	0.173	0.174	0.170	0.172
	(0.520)	(0.621)	(0.550)	(0.548)	(0.556)	(0.551)
Marital status (Reference: Married)						
single	-0.409	-0.483*	-0.346*	-0.349*	-0.354*	-0.358*
	(0.246)	(0.195)	(0.147)	(0.155)	(0.153)	(0.148)
living_separate	-1.911	-1.824	-1.741*	-1.747*	-1.764*	-1.769*
	(1.390)	(0.998)	(0.777)	(0.783)	(0.772)	(0.775)
cohabitant	-0.452	-0.563	-0.308	-0.303	-0.289	-0.284
	(0.987)	(0.890)	(0.828)	(0.828)	(0.816)	(0.820)
widowed	0.176	0.200	0.155	0.150	0.150	0.143
	(0.412)	(0.426)	(0.379)	(0.378)	(0.369)	(0.370)
divorced	-1.085	-0.718	-0.506	-0.511	-0.499	-0.509
	(0.550)	(0.584)	(0.525)	(0.527)	(0.494)	(0.509)
marriage_denied	-0.330	0.0300	-0.0893	-0.0938	-0.167	-0.160
	(0.567)	(1.234)	(1.103)	(1.109)	(1.128)	(1.128)
Employment status (reference: full_time)						
part_time	-0.224	-0.116	-0.0968	-0.0978	-0.0696	-0.0766
	(0.213)	(0.215)	(0.126)	(0.129)	(0.153)	(0.137)
unemployed	-0.137	-0.0151	0.115	0.108	0.104	0.0938
	(0.201)	(0.222)	(0.211)	(0.202)	(0.193)	(0.199)
unemployed_no_job search	-0.657	-0.534	-0.434	-0.428	-0.458	-0.442
	(0.682)	(0.608)	(0.593)	(0.602)	(0.584)	(0.585)
university_student	0.261	0.347	0.374	0.378	0.395	0.398
	(0.253)	(0.269)	(0.274)	(0.279)	(0.280)	(0.281)
retired	-0.162	0.0588	0.109	0.102	0.0825	0.0754
	(0.217)	(0.179)	(0.239)	(0.230)	(0.226)	(0.233)

lookafter_kid	0.145	0.494	0.266	0.260	0.266	0.256
	(0.432)	(0.505)	(0.544)	(0.558)	(0.553)	(0.529)
student	1.177**	1.011**	0.871*	0.872*	0.903**	0.898**
	(0.422)	(0.380)	(0.340)	(0.342)	(0.328)	(0.338)
herder	1.842***	1.423***	1.598***	1.588***	1.499***	1.500***
	(0.244)	(0.266)	(0.263)	(0.230)	(0.270)	(0.267)
health		0.170***	0.133**	0.132**	0.133**	0.132**
		(0.0368)	(0.0397)	(0.0407)	(0.0406)	(0.0391)
environment_satisfaction		0.128**	0.117**	0.117**	0.117**	0.118**
		(0.0336)	(0.0377)	(0.0377)	(0.0380)	(0.0382)
happiness			0.174***	0.174***	0.176***	0.175***
			(0.0393)	(0.0392)	(0.0393)	(0.0393)
sadness			-0.0632*	-0.0629*	-0.0587	-0.0590*
			(0.0283)	(0.0280)	(0.0294)	(0.0291)
rainy				0.0648	-0.147	
				(0.233)	(0.354)	
temperature					0.0213	0.0171
					(0.0166)	(0.00873)
District (reference: Sukhbaatar)						
songinokhairkhan	-0.286**	-0.175	-0.0335	-0.0368	-0.0920	-0.0866
	(0.0926)	(0.118)	(0.0955)	(0.0971)	(0.0905)	(0.0891)
bayanzurkh	-0.587***	-0.548***	-0.406***	-0.398***	-0.360***	-0.355***
	(0.103)	(0.0958)	(0.0634)	(0.0693)	(0.0519)	(0.0508)
bayangol	-0.416***	-0.485***	-0.396**	-0.384**	-0.268	-0.271
	(0.0928)	(0.113)	(0.106)	(0.103)	(0.143)	(0.137)
khan_uul	-0.472**	-0.417**	-0.259	-0.253*	-0.192	-0.196
	(0.149)	(0.159)	(0.132)	(0.125)	(0.133)	(0.127)
chingeltei	-0.846***	-0.818***	-0.591***	-0.589***	-0.571***	-0.571***
	(0.0813)	(0.0861)	(0.0827)	(0.0832)	(0.0805)	(0.0798)
Constant	2.590	1.623	1.383	1.331	1.101	1.061
	(1.305)	(1.588)	(1.657)	(1.507)	(1.600)	(1.661)
Observations	794	779	771	771	771	771
R-squared	0.172	0.234	0.277	0.277	0.278	0.278

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4. Matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) pm10	1.000									
(2) pm25	0.929	1.000								
(3) log_income	-0.031	-0.025	1.000							
(4) education	0.024	0.046	0.262	1.000						
(5) health	-0.023	-0.043	0.077	0.130	1.000					
(6)environment_satisfaction	0.141	0.120	0.077	0.106	0.261	1.000				
(7) happiness	0.091	0.071	0.107	0.047	0.193	0.158	1.000			
(8) sadness	0.245	0.237	-0.034	0.041	-0.176	0.041	-0.274	1.000		
(9) rainy	-0.758	-0.716	0.081	-0.022	0.108	-0.096	-0.014	-0.239	1.000	
(10) temperature	-0.915	-0.860	0.043	-0.056	0.039	-0.160	-0.083	-0.277	0.820	1.000

In the regressions, one dummy variable from each group was omitted in order to avoid perfect multicollinearity. Following Ambrey et al. (2014) age was included as a 4-level categorical variable (age < 25, 25-45, 45-60 and over 60) with the first level as the reference category. Sukhbaatar was omitted from the district group; Buddhist was omitted from religion groups; Khalkh[13] from ethnic groups; married from marital status groups and employed full-time from employment status groups.

In the baseline regression PM10 has a negative coefficient and it is statistically significant at a 1% level, an increase of 10 microgram/m3 in PM10 is associated with a reduction of 0.017 in self-reported LS. This result is consistent with the findings of previous studies (e.g. Zhang et al., 2017; Orru et al., 2016; Ambrey et al., 2014; Ferreira et al., 2013; Levinson, 2012; MacKerron and Mourato, 2009; Welsch 2006). Also consistent with previous literature, wealthier and more educated people report a higher LS. Age does not exhibit a classic U-shaped relationship with LS, however. People aged 45-60 and those over 60 are less happy than the younger age groups[14], i.e. as people in UB get older, they are getting less satisfied with their life. Chuluun et al. (2016) found U-shaped relationship between age and LS using SWB survey data from Orkhon Province[15] in Mongolia which implies further research about this difference between UB and Orkhon.

In terms of religious belief, Buddhists report to be more satisfied with their life compared to atheists. This is unsurprising because Buddhist people tend to be more positive in their responses to life as the causes of happiness in Buddhism are positive thoughts, words and actions (Rydzewska

[13] Khalkh is the main ethnic group in Mongolia which makes up over 90 percent of the population (Raghavan, 2012)
[14] When age is included as a continuous variable its coefficient was negative but insignificant. This was also the case when adding age squared or age squared divided by ten. Results of these regressions are available upon request.
[15] Mongolia has 21 provinces (aimag) and its second biggest city, Erdenet is in Orkhon province. Despite being the second biggest in Mongolia, its population is only 102,160 people and the province in total has around 106,000 according to NSO.

and Reeves, 2015) and the approach that happiness actually arises from embracing the un-satisfactoriness of life or "Duḥkha" (Walsh, 2013).

Compared to the Khalkh ethnic people, the Kazakh ethnic group reports that they are significantly less satisfied with their life. Ethnic minorities may face discrimination, inferiority or harassment as they tend to have different language/dialects, appearance, religion and culture. For example, Pellegrini and Tasciotti (2014) argue that even in Bhutan, which promotes happiness and use of Gross National Happiness Index, the Bhutanese ethnic majority discriminate and harass the Nepali Buthanese ethnic minority. Similarly, Kazakh Mongols might have been experiencing the same issue because they are the largest minority in Mongolia which makes up 4.3 percent of the total population, they are relatively new to Mongolia, and they have different language and religion (Barcus and Werner, 2010). [16]

Regarding employment status, being unemployed has a negative coefficient but it is statistically insignificant. Also, high school students reported a higher LS compared to employed people. Being a herder i.e. nomad is significantly related to higher LS; however, I have only one observation of herder and it is not enough at all to infer any conclusion. Further studies should probably include more nomadic respondents in their survey to see whether they reflect on their life more positively or not.

The district dummies are negative and statistically significant, indicating that individuals in Sukhbaatar district (reference variable in the regression) are more satisfied with their life compared to all the districts included in this study except for Songinokhairkhan. The spatial

[16] The Kazakh migration to Western Mongolia dates from the 1840s. As discussed by Diener (2009), many Kazakh Mongols migrated back to Kazakhstan after the dissolution of the Soviet Union in 1991 and often they were viewed and referred as Mongols by their fellow Kazakhstani Kazakhs because Kazakh Mongols managed to preserve their culture and language to a greater extent than many Kazakhstani Kazakhs whose first language has become Russian. Consequently, they feel dissatisfaction with their homeland because of the difficulty of integrating with Kazakhstani Kazakhs who view them as "others". Similarly, Kazakh Mongols are also viewed as Kazakhs in Mongolia due to their appearance and accent.

dummies capture location-specific factors (other than pollution) that influence LS and help mitigate concerns about omitted variable bias. The fact that they are statistically significant suggests a venue of further research explaining which factors are behind these differences (Ahmadiani et al. 2019).

As discussed in the introduction, PM concentrations have been shown to adversely affect health, which in turn is an important determinant of LS. Thus, in order to see if the effect of PM10 in LS is through health status, I control for it in the regressions. Indeed, PM10 negatively affect individual's self-reported health status when I regressed PM10 and other socioeconomic characteristics on health and the coefficient of PM10 is negative and significant (regression results are provided upon request). In addition, it is possible that those who are less satisfied about the environmental conditions experience a larger marginal effect of air pollution, which is arguably the most pressing environmental problem in UB. The results are reported in column 2. As expected, both control variables are statistically significant, and their coefficients are positive. Those who report to be healthier tend to report a larger LS. People who are more satisfied with their local environment quality also tend be more satisfied with their lives. This seems quite intuitive as concerns about environmental degradation have been shown to affect people's happiness (Ferrer-i-Carbonell and Gowdy, 2007). The key explanatory variable PM10 is consistently significant and its magnitude, at -0.0019, remains practically unchanged.

Next, I control for the effect on happiness of the emotional state in the previous day, i.e. positive and negative affect. These two variables are important because they capture distinct aspects of SWB that are not reflected in more evaluative measures (OECD, 2013). Also, frequent positive affect is necessary for happiness measures (Diener et al., 2009) and temporarily salient factors (mood) that should theoretically have no bearing on the actual quality of a person's life may

influence and systematically bias their reports (Yap et al., 2017). Accordingly, I included whether individuals felt happy or sad in the previous day of survey. The results are presented in column 3. The significance and direction of the coefficients come out as expected. If an individual experienced more happiness in the previous day, their reported LS tends to be higher (statistically significant at 5% level); conversely, a person who reports experienced a sad feeling in the previous day also tends to report a lower LS (significant at 10%). Lastly, PM10 remains significant at 1% and the magnitude of the coefficient is roughly the same as in column 2.

I also controlled for whether the survey was conducted on a rainy day. Controlling for this is rather important because respondents' moods are affected by rainy or sunny day and individuals in good mood tend to show higher LS (Schwarz and Clore, 1983). The results are presented in column 4 and they are robust. Surprisingly, the coefficient of rain is positive and statistically insignificant. The coefficient might be positive because PM10 and rain variables are negatively correlated with each other (ρ=-0.76, refer to Table 4) which means there is less concentration of PM10 on a rainy day and people could have reported higher LS due to reduced air pollution. The magnitude of PM10 coefficient goes from -0.0019 to -0.0017 and it is significant at a 10% level.

In the last two columns, I added outdoor temperature control along with and without rain control, respectively. The coefficient of temperature in both models is positive but insignificant. And the rain coefficient becomes negative in column 5 and it is still insignificant. Overall, the results appear to be quite robust except that in the models where I control for temperature, PM10 loses its significance as these two variables are strongly correlated (ρ=-0.91). The VIFs for the fifth and sixth models with both pollution and temperature variables are over 10 and 9.7 for both variables, respectively (table A5). As discussed in the introduction, the burning of coal in the Ger and resulting air pollution occur in winter and not in summer. Unfortunately, I would need more

geographical or temporal variation to disentangle the temperature and pollution effects, which are intertwined in our UB sample. Due to the temperature and pollution collinearity my reference model for the calculation of the monetary estimates is that in column (4), which controls for health and environment satisfaction, previous-day emotional state and rain.

5.1. Monetary estimates

I can now calculate pollution exposed individual's WTP for better air quality by calculating the MRS between income and PM10. By using coefficient -0.0017 of PM10 and 0.222 of log form of income as well as 5,730,000MNT of annual mean per capita income, the resulting annual average WTP of UB residents for a 10 $\mu g/m^3$ (0.01 mg/m^3) reduction in daily average air pollution is about 438,000 MNT which is equivalent to $191 and daily WTP is 1,200 MNT ($0.5). [17] The average concentration of PM10 during the survey days was 177 $\mu g/m^3$; thus, 438,000 MNT is an amount that an individual would pay annually for a 5.6% reduction in 24-hour mean PM10 concentration. Similarly, in order to bring the 24-hour mean concentration to WHO guidelines value (50 $\mu g/m^3$), UB people are willing to pay over 5 million MNT annually.

This finding could not only be a base for further research studies of non-market valuation of air quality in UB and Mongolia, but it is also comparable to other studies conducted in different countries. Levinson (2012) estimated annual WTP of $891 (in 2012 USD) for a 1$\mu g/m^3$ reduction in pm10 which is $8,910 for 10$\mu g/m^3$ reduction in the USA by exploiting the same approach. My estimates are smaller than Levinson's, but still sizeable, especially provided that the average annual income in Mongolia is much lower compared to USA. Similarly, Ambrey et al. (2014) estimated annual average household WTP of about 5,000 AUD for a one-day decrease in the average number of days that the PM10 exceeds national health guidelines.

[17] MNT to USD exchange rate is calculated as the average exchange rate between June 2016 and February 2017 which are the survey periods. The average was 1USD=2291.25MNT (Source: Bank of Mongolia database)

A ban on raw coal burning has been in effect since May 15th, 2019. NSO of Mongolia reported that average PM10 concentration decreased by respectively 106 μg/m^3, 120 μg/$m^3$and 97 μg/m^3 in December 2019, January and February 2020 compared to previous one year each. Thus, the average reduction during the three most polluted months is roughly 108 μg/m^3. In a back of the envelope calculation, if we translate this reduction into monetary terms using my findings, it would be about 4,730,000 MNT ($2065) per person. Considering that UB has 1,491,375 official residents as of 2018 (NSO of Mongolia, 2020), average reduction in pm10 concentration during the most polluted 3 months could be valued as roughly 7 trillion MNT ($3 billion USD).

CHAPTER 6

CONCLUSION AND FURTHER RESEARCH

The rapid growth of the capital of Mongolia, Ulaanbaatar has been accompanied by deadly air pollution for more than a decade because its unique city characteristics. Among different air pollutants, particulate matter has been the most serious threat to the health of UB residents. Although much research has documented its adverse health outcomes, this is the first attempt to estimate the effect of air pollution on individual's well-being in UB.

I used repeated cross-sectional data from the first ever Mongolian-wide social well-being survey. The survey contains a self-reported life satisfaction question as well as a wealth of information of individual characteristics. I match life satisfaction to the air pollution readings from 12 monitoring stations spread around the city as well as meteorological data and other socioeconomic controls, to evaluate how life satisfaction varies with different air pollution exposures.

Consistent with previous studies, I find a negative and significant relationship between air pollution and self-reported well-being. 10 $\mu g/m^3$ increase in PM10 concentration is associated with 0.017 points reduction in individual's self-reported life satisfaction of 11-point scale. The sign, significance and magnitude of this effect is robust in different model specifications, except when temperature, which is almost perfectly correlated with PM10 concentrations, was controlled for.

In addition, I calculated the WTP of UB residents to reduce exposure to PM10 by computing the MRS between income and the pollution variable, i.e. the rate at which an individual

is willing to trade off income against air pollution at the margin. The average annual WTP for a reduction in daily mean PM10 concentration by 10 $\mu g/m^3$ (0.01 mg/m^3) is 438,000 MNT ($191), and over 5 million MNT to bring the air quality in UB up to the WHO guidelines. According to my numbers, recently implemented ban on raw coal burning is translated into 7 trillion MNT for an average monthly reduction in PM10 concentration of 108 $\mu g/m^3$ over the past period of December 2019-February 2020 and our results indicate that ban on raw coal has greatly contributed to the welfare of UB residents.

Due to lack of data, this study did not manage to fully capture unobserved heterogenous individual traits; thus, further studies may address this issue by using panel survey data on subjective well-being which Mongolia has not been quite pursuing consistently. Furthermore, more precise measurement or disaggregated level of individual's exposure to air pollution would be always preferable for the relationship between pollution and LS or happiness. Nevertheless, the present study suggests that air pollution plays a significant role in determining intra-country differences in subjective well-being and the effect of air pollution in UB translates into a considerable monetary value for its people.

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APPENDIX

Table A1. Description of variables

Variables	Description
Survey variables	
district	District (1=Songinokhairkhan, 2=Bayanzurkh, 3=Bayangol, 4=khan-Uul, 5=Sukhbaatar, 6=Chingeltei)
age	Age of the respondent
age2	Age squared
age1325	1 if the respondent is aged between 13-24, 0 otherwise
age2545	1 if the respondent is aged between 25-44, 0 otherwise
age4560	1 if the respondent is aged between 45-59, 0 otherwise
age60	1 if the respondent is aged over 60, 0 otherwise
male	1 if the respondent is male
family	Number of household members
yearsliving	Number of years living in the current place
education	Education level (1=illiterate, 2=illiterate but did not attend any school, 3=elementary, 4=middle, 5=secondary, 6=vocational, 7=specialized professional, 8=diploma, 9=bachelor 10=master, 11=phd
LS	Life satisfaction between 0-10 (0=not satisfied at all, 10=completely satisfied)
log_income	Log form of individual income
songinokhairkhan	1 if the respondent is from the district of Songinokhairkhan, 0 otherwise
bayanzurkh	1 if the respondent is from the district of Bayanzurkh, 0 otherwise
bayangol	1 if the respondent is from the district of Bayangol, 0 otherwise
khan_uul	1 if the respondent is from the district of Khan-Uul, 0 otherwise
sukhbaatar	1 if the respondent is from the district of Sukhbaatar, 0 otherwise
chingeltei	1 if the respondent is from the district of Chingeltei, 0 otherwise
atheist	1 if the respondent is atheist, 0 otherwise
buddhist	1 if the respondent is Buddhist, 0 otherwise
christian	1 if the respondent is Christian, 0 otherwise
muslim	1 if the respondent is Muslim, 0 otherwise
shamanist	1 if the respondent is Shamanist, 0 otherwise
other_religion	1 if the respondent believes in other religion than above
khalkh	1 if the respondent is Khalkh, 0 otherwise
kazakh	1 if the respondent is Kazakh, 0 otherwise
durvud	1 if the respondent is Durvud, 0 otherwise
buriat	1 if the respondent is Buriat, 0 otherwise
bayad	1 if the respondent is Bayad, 0 otherwise
dariganga	1 if the respondent is Dariganga, 0 otherwise
urianhai	1 if the respondent is Urianhai, 0 otherwise
zakhchin	1 if the respondent is Zakhchin, 0 otherwise
other_ethnic	1 if the respondent is of other ethnic than above, 0 otherwise
illiterate	1 if the respondent is illiterate, 0 otherwise
literate_noschool	1 if the respondent is literate but did not attend school, 0 otherwise
single	1 if the respondent is single, 0 otherwise
married	1 if the respondent is married, 0 otherwise
living_separate	1 if the respondent is married but living separately, 0 otherwise
cohabitant	1 if the respondent is cohabitant, 0 otherwise
widowed	1 if the respondent is widowed, 0 otherwise

divorced	1 if the respondent is divorced, 0 otherwise
marriage_denied	1 if the respondent's marriage has been denied, 0 otherwise
full_time	1 if the respondent is employed full-time, 0 otherwise
part_time	1 if the respondent is employed part-time, 0 otherwise
unemployed	1 if the respondent is unemployed, 0 otherwise
unemployed_nojobsearch	1 if the respondent is unemployed and not looking for a job, 0 otherwise
university_student	1 if the respondent is an university student, 0 otherwise
retired	1 if the respondent is retired, 0 otherwise
lookafter_sick	1 if the respondent is looking after sick person, 0 otherwise
lookafter_kid	1 if the respondent is looking after a kid, 0 otherwise
student	1 if the respondent is a student but not university student, 0 otherwise
herder	1 if the respondent is a herder, 0 otherwise
health	Respondent's satisfaction with their own health condition on 0-10 (0=not satisfied at all, 10=completely satisfied)
environment_satisfaction	Respondent's satisfaction with their local environment on 0-10 (0=not satisfied at all, 10=completely satisfied)
sadness	Whether the respondent felt sad on the previous day of interview on 0-10 (0=not at all, 10=all day)
happiness	Whether the respondent felt happy on the previous day of interview on 0-10 (0=not at all, 10=all day)
Pollution variables	
pm10	PM10 concentration in $\mu g/m^3$
pm25	PM2.5 concentration in $\mu g/m^3$
Meteorological variables	
temperature	Temperature in Celsius
rainy	1 if the respondent was surveyed on a rainy day, 0 otherwise

Table A2. Summary of key variables on each of the surveyed days

	6/10/2016	**6/11/2016**	**6/12/2016**	**6/13/2016**	***2/2/2017***	***2/3/2017***	***2/4/2017***
Life satisfaction	6.397	6.867	7.374	7.901	6.985	6.89	7.089
PM2.5	33.273	37.349	31.353	26.391	245.4	324.421	269.22
PM10	45.013	67.433	64.538	67.763	332.254	410.158	318.333
Rain	1	0	1	1	0	0	0
Temperature	12.3	13.2	13.7	13.4	-18.3	-17.8	-18.8

Table A3. Ordered-probit regression results

VARIABLES	(1) Baseline Regression	(2) + Health & environment satisfaction	(3) + Health & env satisfaction & previous day mood	(4) + Health & env satisfaction & previous day mood +rain	(5) + Health & env satisfaction & previous day mood +rain +temp	(6) + Health & env satisfaction & previous day mood +temp
pm10	-0.00116***	-0.00130***	-0.00129***	-0.00120***	-0.000413	-0.000431
	(0.000127)	(0.000164)	(0.000222)	(0.000388)	(0.000526)	(0.000503)
log_income	0.159***	0.148***	0.130***	0.129***	0.129***	0.128***
	(0.0351)	(0.0392)	(0.0386)	(0.0402)	(0.0397)	(0.0384)
age2545	-0.238***	-0.181***	-0.125**	-0.123*	-0.113*	-0.112*
	(0.0606)	(0.0673)	(0.0626)	(0.0682)	(0.0625)	(0.0611)
age4560	-0.336***	-0.239***	-0.134	-0.120	-0.160	-0.131
	(0.122)	(0.0922)	(0.125)	(0.138)	(0.144)	(0.122)
age_over60	-0.406**	-0.293**	-0.293**	-0.291**	-0.257**	-0.261**
	(0.182)	(0.137)	(0.123)	(0.124)	(0.123)	(0.122)
male	0.0460	0.0395	0.0145	0.0140	0.0198	0.0179
	(0.0457)	(0.0776)	(0.0848)	(0.0862)	(0.0894)	(0.0858)
family	0.0264	0.0155	0.00783	0.00798	0.00710	0.00748
	(0.0396)	(0.0377)	(0.0292)	(0.0291)	(0.0289)	(0.0287)
yearsliving	0.000511	0.000882	0.00121	0.00118	0.00118	0.00113
	(0.00405)	(0.00472)	(0.00502)	(0.00505)	(0.00508)	(0.00499)
education	0.0950***	0.0714***	0.0745***	0.0748***	0.0765***	0.0766***
	(0.0161)	(0.0144)	(0.0153)	(0.0152)	(0.0144)	(0.0145)
atheist	-0.121	-0.161**	-0.163**	-0.165**	-0.168**	-0.171***
	(0.0819)	(0.0747)	(0.0653)	(0.0693)	(0.0690)	(0.0659)
christian	-0.320*	-0.321*	-0.258	-0.259	-0.274	-0.272
	(0.193)	(0.187)	(0.177)	(0.178)	(0.175)	(0.176)
muslim	0.595	0.980*	0.904*	0.903*	0.894*	0.894*
	(0.373)	(0.504)	(0.523)	(0.524)	(0.519)	(0.523)
shamanist	-0.299	-0.257	-0.228	-0.229	-0.229	-0.231
	(0.266)	(0.271)	(0.263)	(0.265)	(0.266)	(0.265)
kazakh	-1.100***	-1.051***	-1.101***	-1.104***	-1.098***	-1.104***
	(0.275)	(0.293)	(0.278)	(0.279)	(0.269)	(0.276)
durvud	0.279	0.280**	0.305	0.306	0.300	0.303*
	(0.174)	(0.135)	(0.194)	(0.193)	(0.186)	(0.184)
buriat	-0.112	-0.103	-0.0550	-0.0573	-0.0618	-0.0642
	(0.382)	(0.332)	(0.263)	(0.268)	(0.261)	(0.259)
bayad	-0.416*	-0.478	-0.361	-0.366	-0.366	-0.373
	(0.252)	(0.374)	(0.400)	(0.398)	(0.401)	(0.404)
dariganga	0.410	0.362	0.249	0.253	0.258	0.263
	(0.520)	(0.537)	(0.543)	(0.542)	(0.560)	(0.559)
zakhchin	-0.620	-0.473	0.129	0.130	0.142	0.141
	(0.824)	(0.705)	(0.471)	(0.464)	(0.459)	(0.454)
other_ethnic	0.512	0.276	0.170	0.171	0.165	0.167
	(0.322)	(0.372)	(0.342)	(0.340)	(0.341)	(0.341)
single	-0.142	-0.183**	-0.111*	-0.113*	-0.116*	-0.118**
	(0.0954)	(0.0720)	(0.0568)	(0.0583)	(0.0591)	(0.0586)
living_separate	-0.902	-0.887**	-0.884**	-0.886**	-0.899**	-0.901**
	(0.615)	(0.449)	(0.368)	(0.373)	(0.362)	(0.365)
cohabitant	-0.188	-0.244	-0.112	-0.110	-0.103	-0.101
	(0.465)	(0.432)	(0.415)	(0.414)	(0.409)	(0.411)

widowed	0.0836	0.0978	0.0784	0.0761	0.0752	0.0720
	(0.207)	(0.221)	(0.203)	(0.202)	(0.197)	(0.198)
divorced	-0.431*	-0.237	-0.142	-0.145	-0.137	-0.142
	(0.247)	(0.260)	(0.234)	(0.235)	(0.215)	(0.224)
marriage_denied	-0.161	0.0214	-0.0446	-0.0470	-0.0840	-0.0805
	(0.222)	(0.563)	(0.529)	(0.532)	(0.540)	(0.541)
part_time	-0.123	-0.0784	-0.0606	-0.0609	-0.0466	-0.0497
	(0.112)	(0.122)	(0.0782)	(0.0793)	(0.0904)	(0.0831)
unemployed	0.0100	0.0790	0.153	0.149	0.148	0.142
	(0.108)	(0.118)	(0.112)	(0.104)	(0.0992)	(0.105)
unemployed_nojobsearch	-0.339	-0.295	-0.248	-0.245	-0.260	-0.252
	(0.301)	(0.281)	(0.279)	(0.283)	(0.274)	(0.274)
university_student	0.0913	0.130	0.150	0.152	0.161	0.163
	(0.107)	(0.124)	(0.124)	(0.125)	(0.127)	(0.128)
retired	-0.0458	0.0715	0.109	0.106	0.0938	0.0917
	(0.0933)	(0.0674)	(0.0892)	(0.0850)	(0.0823)	(0.0856)
lookafter_kid	0.122	0.314	0.191	0.188	0.193	0.188
	(0.245)	(0.288)	(0.320)	(0.325)	(0.324)	(0.313)
student	0.574***	0.506***	0.447***	0.447***	0.462***	0.459***
	(0.210)	(0.179)	(0.167)	(0.168)	(0.164)	(0.169)
herder	0.738***	0.547***	0.652***	0.646***	0.599***	0.599***
	(0.115)	(0.138)	(0.129)	(0.111)	(0.138)	(0.138)
health		0.0869***	0.0702***	0.0698***	0.0703***	0.0697***
		(0.0191)	(0.0212)	(0.0217)	(0.0217)	(0.0209)
environment_satisfaction		0.0646***	0.0617***	0.0618***	0.0623***	0.0623***
		(0.0169)	(0.0188)	(0.0187)	(0.0189)	(0.0190)
happiness			0.0892***	0.0892***	0.0903***	0.0901***
			(0.0205)	(0.0205)	(0.0205)	(0.0205)
sadness			-0.0380**	-0.0379**	-0.0357**	-0.0359**
			(0.0170)	(0.0168)	(0.0176)	(0.0174)
rainy				0.0374	-0.0755	
				(0.122)	(0.184)	
temperature					0.0112	0.00907*
					(0.00902)	(0.00512)
songinokhairkhan	-0.145***	-0.0828	-0.0108	-0.0127	-0.0423	-0.0394
	(0.0521)	(0.0666)	(0.0570)	(0.0582)	(0.0525)	(0.0527)
bayanzurkh	-0.297***	-0.284***	-0.217***	-0.212***	-0.193***	-0.190***
	(0.0601)	(0.0587)	(0.0396)	(0.0419)	(0.0354)	(0.0351)
bayangol	-0.238***	-0.282***	-0.238***	-0.230***	-0.168**	-0.170**
	(0.0494)	(0.0571)	(0.0528)	(0.0504)	(0.0793)	(0.0767)
khan_uul	-0.265***	-0.247***	-0.177**	-0.173**	-0.140*	-0.142*
	(0.0764)	(0.0859)	(0.0769)	(0.0728)	(0.0808)	(0.0785)
chingeltei	-0.392***	-0.384***	-0.280***	-0.278***	-0.269***	-0.269***
	(0.0413)	(0.0401)	(0.0381)	(0.0387)	(0.0385)	(0.0382)
/cut1	0.255	0.756	0.866	0.896	1.017	1.037
	(0.601)	(0.688)	(0.744)	(0.665)	(0.690)	(0.721)
/cut2	0.279	0.782	0.894	0.924	1.044	1.064
	(0.581)	(0.671)	(0.726)	(0.646)	(0.674)	(0.704)
/cut3	0.489	1.011	1.136	1.165*	1.287*	1.307*
	(0.577)	(0.670)	(0.722)	(0.643)	(0.670)	(0.699)
/cut4	0.762	1.293*	1.435**	1.465**	1.588**	1.608**

	(0.570)	(0.680)	(0.730)	(0.647)	(0.675)	(0.707)
/cut5	1.005*	1.547**	1.705**	1.735***	1.858***	1.878***
	(0.566)	(0.664)	(0.726)	(0.640)	(0.672)	(0.706)
/cut6	1.507**	2.072***	2.248***	2.278***	2.402***	2.422***
	(0.593)	(0.697)	(0.745)	(0.662)	(0.689)	(0.721)
/cut7	1.925***	2.503***	2.697***	2.727***	2.852***	2.871***
	(0.589)	(0.677)	(0.734)	(0.651)	(0.682)	(0.713)
/cut8	2.477***	3.071***	3.281***	3.311***	3.436***	3.455***
	(0.596)	(0.678)	(0.743)	(0.660)	(0.695)	(0.727)
/cut9	3.027***	3.639***	3.861***	3.891***	4.016***	4.036***
	(0.584)	(0.654)	(0.711)	(0.629)	(0.661)	(0.693)
/cut10	3.323***	3.954***	4.187***	4.217***	4.342***	4.362***
	(0.609)	(0.677)	(0.730)	(0.649)	(0.680)	(0.711)
Observations	794	779	771	771	771	771

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A4a. Baseline regression with both pollutants

VARIABLES	(1) Baseline Regression
pm10	-0.00129
	(0.000673)
pm25	-0.000556
	(0.000766)
log_income	0.303**
	(0.0818)
age2545	-0.509***
	(0.0978)
age4560	-0.750*
	(0.308)
age_over60	-0.906*
	(0.377)
male	0.0651
	(0.0994)
family	0.0437
	(0.0822)
yearsliving	0.000780
	(0.00723)
education	0.197***
	(0.0351)
atheist	-0.278
	(0.162)
christian	-0.680
	(0.452)
muslim	1.642
	(0.917)
shamanist	-0.605
	(0.563)
kazakh	-2.475**
	(0.799)
durvud	0.575
	(0.349)
buriat	-0.136
	(0.777)
bayad	-0.666
	(0.482)
dariganga	0.859
	(0.861)
zakhchin	-1.702
	(2.158)
other_ethnic	0.882
	(0.520)
single	-0.409
	(0.246)
living_separate	-1.903
	(1.390)
cohabitant	-0.454
	(0.986)
widowed	0.183
	(0.411)
divorced	-1.084

	(0.553)
marriage_denied	-0.349
	(0.588)
part_time	-0.223
	(0.213)
unemployed	-0.137
	(0.203)
unemployed_nojobsearch	-0.660
	(0.680)
university_student	0.264
	(0.253)
retired	-0.162
	(0.218)
lookafter_kid	0.149
	(0.432)
student	1.173**
	(0.422)
herder	1.834***
	(0.243)
songinokhairkhan	-0.235**
	(0.0833)
bayanzurkh	-0.559***
	(0.0943)
bayangol	-0.378***
	(0.0827)
khan_uul	-0.432**
	(0.136)
chingeltei	-0.823***
	(0.0673)
Constant	2.549
	(1.282)
Observations	794
R-squared	0.172

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A4b. Variance inflation factor

	VIF	1/VIF
pm25	11.485	.087
pm10	11.354	.088
age over60	3.379	.296
age2545	3.277	.305
age4560	3.227	.31
songinokhairkhan	2.618	.382
retired	2.596	.385
single	2.483	.403
university student	2.446	.409
bayanzurkh	2.125	.471
bayangol	2.087	.479
khan uul	1.741	.575
chingeltei	1.673	.598
student	1.538	.65
education	1.365	.733
widowed	1.345	.744
muslim	1.266	.79
kazakh	1.249	.801
unemployed_nojobsearch	1.241	.806
male	1.18	.848
log_income	1.175	.851
part time	1.161	.861
divorced	1.145	.873
atheist	1.138	.879
lookafter kid	1.134	.882
unemployed	1.125	.889
cohabitant	1.112	.899
yearsliving	1.102	.907
family	1.102	.908
shamanist	1.094	.914
christian	1.076	.93
other ethnic	1.048	.954
durvud	1.037	.965
buriat	1.036	.965
dariganga	1.036	.965
bayad	1.033	.968
living separate	1.032	.969
herder	1.03	.971
marriage denied	1.027	.974
zakhchin	1.014	.986
Mean VIF	2.033	.

Table A5. VIF of model with "rain and temp controls" (left) and model with "temp control only"(right)

	VIF	1/VIF
temperature	13.639	.073
pm10	10.381	.096
rainy	5.019	.199
age4560	3.831	.261
age over60	3.437	.291
age2545	3.359	.298
retired	2.614	.383
single	2.53	.395
university student	2.503	.399
bayangol	2.047	.489
bayanzurkh	2.005	.499
songinokhairkhan	1.887	.53
chingeltei	1.585	.631
student	1.574	.635
khan uul	1.571	.637
education	1.414	.707
health	1.346	.743
widowed	1.335	.749
sadness	1.319	.758
unemployed nojobsearch	1.286	.778
muslim	1.281	.781
kazakh	1.263	.792
happiness	1.249	.801
log income	1.201	.832
environment satisfaction	1.199	.834
male	1.18	.848
part time	1.178	.849
divorced	1.172	.853
lookafter kid	1.158	.863
atheist	1.157	.864
unemployed	1.141	.876
cohabitant	1.124	.889
family	1.111	.9
shamanist	1.11	.901
yearsliving	1.109	.902
christian	1.083	.923
other ethnic	1.071	.934
bayad	1.05	.952
dariganga	1.04	.961
living separate	1.039	.963
durvud	1.039	.963
herder	1.036	.965
buriat	1.035	.966
marriage denied	1.031	.97
zakhchin	1.021	.98
Mean VIF	2.061	.

	VIF	1/VIF
pm10	10.354	.097
temperature	9.781	.102
age over60	3.436	.291
age2545	3.358	.298
age4560	3.321	.301
retired	2.611	.383
single	2.527	.396
university student	2.502	.4
bayangol	2.046	.489
bayanzurkh	2.001	.5
songinokhairkhan	1.883	.531
chingeltei	1.585	.631
student	1.573	.636
khan uul	1.57	.637
education	1.414	.707
health	1.338	.747
widowed	1.333	.75
sadness	1.318	.759
muslim	1.281	.781
unemployed nojobsearch	1.272	.786
kazakh	1.26	.794
happiness	1.247	.802
log income	1.199	.834
environment satisfaction	1.199	.834
male	1.175	.851
part time	1.174	.852
divorced	1.168	.856
lookafter kid	1.155	.866
atheist	1.153	.867
unemployed	1.137	.879
cohabitant	1.124	.89
family	1.11	.901
shamanist	1.11	.901
yearsliving	1.108	.903
christian	1.083	.923
other ethnic	1.071	.934
bayad	1.047	.955
dariganga	1.04	.962
living separate	1.038	.963
durvud	1.038	.963
herder	1.036	.965
buriat	1.035	.966
marriage denied	1.031	.97
zakhchin	1.021	.98
Mean VIF	1.892	.